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Implementing the Gulf of Maine Ocean Observing System  
Final Report  
Submitted to the Office of Naval Research  
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## OVERVIEW

Funds submitted in 2000 to implement an ocean observing system for the Gulf of Maine have resulted in the organization widely known as GoMOOS. The technical program, implemented by scientists at University of Maine, Bigelow Laboratory of Ocean Sciences, Bedford Institute of Oceanography and Woods Hole Oceanographic Institution, includes 10 buoys collecting real-time observations of the ocean and atmosphere, satellite predictive models of waves and circulation, testing of new technologies for monitoring nutrients and zooplankton, coordination of a variety of satellite measurements, a data management system to integrate all the data streams, a website to disseminate the information, a non-profit organization with over 30 member institutions representing the wide variety of users who need the data, and a headquarters in Portland, Maine that coordinates all the activities.

The system works. Its hourly data have become routinely available via [www.gomoos.org](http://www.gomoos.org), NOAA weather radio, the National Data Buoy Center's dial-a-buoy service, television weather forecasters, the weather page of Portland Press Herald's website: [www.maintoday.com](http://www.maintoday.com), the buoy data pages at [www.maineharbors.com](http://www.maineharbors.com), the buoy data page at [www.fishresearch.org](http://www.fishresearch.org), the NDBC buoy-data pages, and others. The data are in active use for monitoring water quality in Massachusetts Bays by the Massachusetts Water Resources Administration, for monitoring environmental conditions relevant to aquaculture in Eastport, Maine, for marine research at the University of New Hampshire and other research institutions in the region, for safe marine operations by Penobscot Bay and Pilots Association, for sea-going activities of the United States Coast Guard who collectively represent one of the biggest users of the GoMOOS website, and for myriad other uses and users throughout the region. The applications are growing in both the public and private sectors. The system has filled a void as a public service utility.

## DISTRIBUTION STATEMENT A

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The single observing system serves immediate needs for ocean and atmospheric conditions for safe marine operations; it provides long-term research-quality records that will be used to assess and predicting fish stocks, detecting coastal climate change; and it has been improving weather prediction and safety on shore. The weather forecast offices (WFOs) of the National Weather Service have been using GoMOOS data to adjust their forecasts and improve their skill targets. The following testimonies come from an exchange between NOAA forecast officials, "The new GoMOOS buoy off Gloucester, especially, helped WFO Taunton staff this weekend to assess the building seas and alert officials to expected splashover at time of high tide Sunday morning. Indeed, the increase to 19 foot seas at the Gloucester buoy heralded spotty flooding/debris along shore roads where the breakers sent spray over sea walls." The model forecast predictions alone would have underestimated the actual potential for damage and the needed emergency response. The benefits work in the other direction as well: "In an earlier event this month, the slowness of seas to build at the Gloucester and Boston buoys helped us convey to emergency management (EM) officials with greater confidence that the coastal flooding would likely be less severe with little in way of structural damage...This again seems to say the in situ observations helped adjust the forecast to get better accuracy and a better skill score. It also talks to another important point...you convinced the EM that the effect would be less than forecast...you were able to lower the projected impact of the warning...over-warning costs money. Here we were able to limit the overwarning. That saved someone real money."

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## General Overview

### *Background*

Based on the findings of two recent reports commissioned by the National Ocean Research Leadership Council (Nowlin and Malone, April 1999; Frosch et al., December 1999), the United States is on the verge of launching a national coastal ocean observing system. NORLC's program unit, the National Ocean Partnership Program, has established a national coordinating office (known as Ocean.US) to put into place the framework of the system.

The technology that will drive the system is still evolving, but many requirements are available and tested. This technology has proven its value in efforts ranging from the vast Tropical Ocean Atmospheric Array in the equatorial Pacific to the regional scale multipurpose GoMOOS array and finally to the small but intensive test beds such as LEO-15 off the coast of New Jersey and the Martha's Vineyard Coastal Observatory off of Cape Cod. These and many other systems are employing combinations of satellite technology, *in situ* measurements from moored buoys, autonomous underwater vehicles, and shipboard surveys. Most are single purpose and/or short-term research projects, but they are successfully collecting meteorological, physical oceanographic, and, to lesser extents, chemical and biological observations of the oceans. Provided that the observations can be continuous and ongoing – the fundamental purpose of the movement toward a sustained coastal ocean observing system -- they will be the foundation for increasingly sophisticated models that can predict events, from the recruitment of fish stocks to the trajectory of oil spills.

As conceived by the intellectual leaders in the movement toward a comprehensive coastal ocean observing system, the system will build on the many fragmentary pieces already in place. Special attention is being given to three basic components of the system: the collection of observations, the communications and management of data, and the translation of the data into useful products through data assimilation and analysis.

However, these technical pieces of the system will not themselves create the system. An institutional arrangement is needed to put the pieces into place, govern the system, gain the credibility of national governments and other sources of sustained funding, and assure that the system will meet the day-to-day needs of users who depend on the coastal ocean for their livelihoods and well-being.

### *GoMOOS: From Research to Utility*

The broad outline leaves a lot of room for the design of the regional entities that will make up the national system. And here the challenge is substantial, because there is little experience or language in the world of oceanography to describe what these entities might look like and how they might be governed. The good will and collegiality that binds researchers during research projects will not meet the requirements of a sustained operational system. A coordinated national system needs more than the endurance, vision and independence of a few tenured stalwarts who support their systems on research grants. The only language available to the research community is that of the research

world. As a result, almost all of the existing ocean observing systems are based on a research paradigm. In that paradigm:

- The system is led by a scientist based at an academic or other scientific institution;
- The principal purpose of the observations is the discovery of knowledge;
- The principal customers of the system are researchers, and the decisions of what to observe, and how, brings the broad range of users in as an afterthought;
- The systems depend on a series of short-term, competitive grants;
- The infrastructure vanishes after 3-5 years.

When the Gulf of Maine Ocean Observing System was first conceived, it was conceived in this language. But soon the founders realized that a different paradigm was needed. The research model was limited especially in three ways. First, existing research organizations in the Gulf of Maine region naturally were suspicious of what appeared to be the creation of a competing organization, one that would survive only if it ate into the same resources upon which existing universities and research labs depend. It became clear that the Gulf of Maine region – already blessed with renowned marine research organizations and universities – did not need another one. Rather, what the region needed was infrastructure that would enable the existing organizations to pursue their work more effectively.

Second, under the research model, the assets of the system – the moored buoys and other equipment -- would be deployed to answer research questions. It would be assumed that the observations and predictive capacity thus gained would be useful to other sectors as well, including shipping, the fisheries, search and rescue, and so forth. But such spin-off benefits would be incidental, not primary. Yet, to sustain long-term support and funding requires that many user groups see the system as essential to them, designed specifically to help them solve their day-to-day problems in real time.

Third, the research model did not provide a path to operations. It was difficult to project how it would evolve into a 24-by-7 real-time operation, when such a mode is inconsistent with the mission and objectives of the principal investigators and their academic or research institutions. Whereas a successful research project can leave all its results until publication at the end of the grant period, a useful operational system becomes one upon which users depend for timely delivery of information. The operational system cannot go away on weekends, it cannot wait for quality control, and it cannot become secondary in priority to some other project. Users, including researchers, desperately need data records that exceed the duration of typical research grants, but many users also need the timely delivery of quality information. The maintenance requirements of such a system provide unfamiliar and costly demands on the research world.

Thus, a different model was required. The founders of GoMOOS turned to the model of a utility cooperative. Its paradigm is, in many ways, the converse of the research model. Yet, paradoxically, the research community stands to be one of the biggest users and beneficiaries of the system. In the new paradigm:

- Rather than a research endeavor that creates its own single-purpose infrastructure, GoMOOS is an infrastructure project – not unlike the deployment of a telecommunications system or an electrical grid – that will benefit many users, including researchers.
- Rather than a mission defined solely by the pursuit of knowledge, its mission includes the collection of data, creation of data products, and dissemination of useful information upon which many, including researchers, can rely for a variety of purposes.
- Rather than targeted solely to the needs of a small group of researchers in search of knowledge about a single process, it is targeted to the entire ocean science community, along with an array of users whose needs can be determined by traditional market analysis.
- Rather than led by a scientist burdened with managerial responsibilities, it is led by a chief executive officer who understands researchers' needs and who relies upon a team of scientists who provide the technical expertise to design, implement and oversee the system.
- Rather than a research organization whose independent projects are governed by principal investigators, it is a service organization governed by a board of directors, with contracts awarded to scientists who can design and deploy the system according to specifications needed to meet its multi-purpose mission.
- Rather than burden individual scientists with the responsibility of obtaining funds to support the infrastructure, it becomes the purpose of the board of directors to collectively acquire the funds.
- Rather than rely on short-term competitive grants, it requires long term line-item funding to provide the foundation for sustained operations.

#### *GoMOOS, Inc.*

The Gulf of Maine Ocean Observing System (GoMOOS, Inc.) is a nonprofit corporation. It is a membership organization whose charter members came together to create a system that speaks to the needs of each – whether to facilitate research, manage fisheries, monitor water quality, or improve the safety of mariners. The breadth of interest in a system is represented by the breadth of sectors among the charter members: shipping companies and services, universities, colleges, and marine research organizations, fishing concerns, water and resource management agencies, petroleum industry, technology companies, and public service organizations like aquariums.

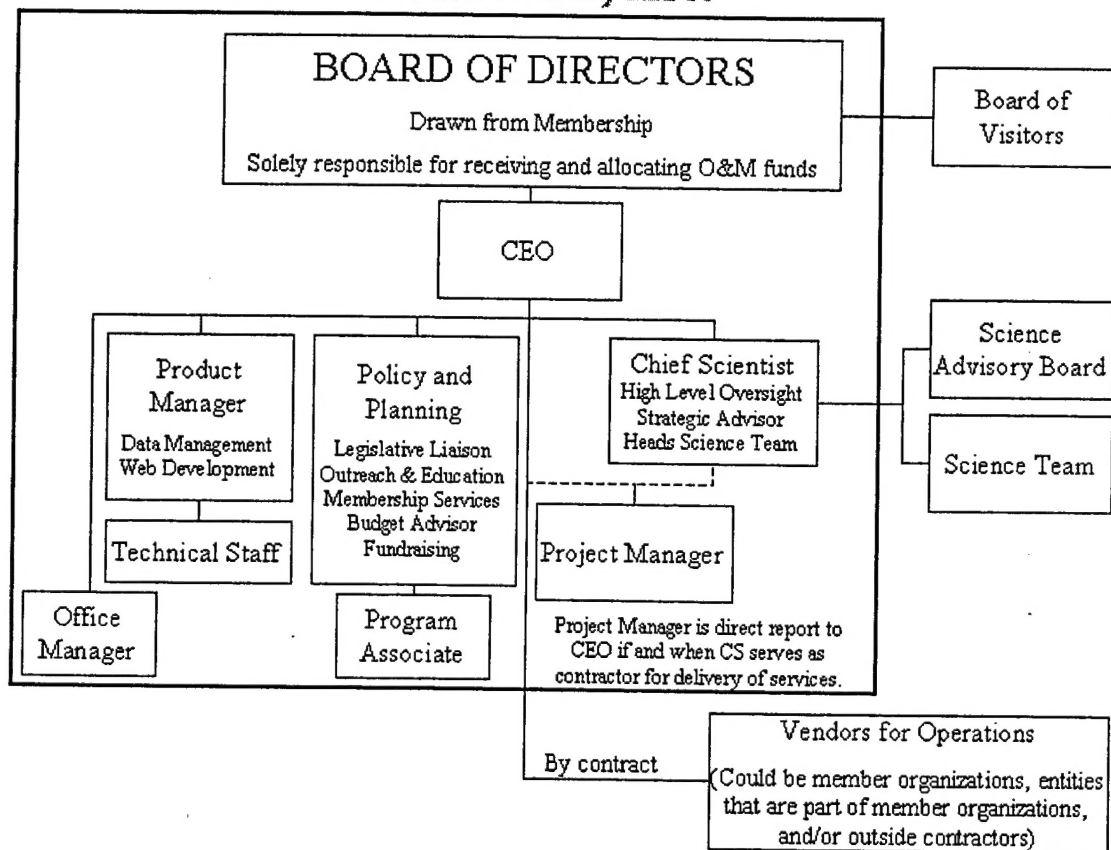
Although GoMOOS is a membership organization, the observations gathered and the information products developed from it are made available to the public on a free and open basis. Membership is motivated not by the prospect of gaining access to proprietary information, but rather by a self-enlightened interest to create a system that otherwise would not exist, a system to collect observations vital to individual corporate, research, management, or educational needs, a system of which we would otherwise be deprived because no one else is going to do it. In this sense, the system is a cooperative utility.

The purpose of having GoMOOS incorporate as a 501(c)(3) was to allow the participants to act collectively like an individual, to take on fiduciary responsibilities and to assume

liabilities. The corporate structure also ensures a plan of succession, insulating the system from departures or retirements of key individuals. This is essential to sustained "24/7" thinking.

The GoMOOS Board of Directors has clear responsibilities. Consistent with those responsibilities, the Board and the organization work to obtain funds to develop and operate the system. This is a fundamental departure from the research paradigm where the scientists obtain the funds. Founding members chose to have institutions represented on the Board because institutions have the staying power for an operational system, and the organization has collectively more power than any of the individual institutions. The individuals on the board represent their institutions. When scientists are given decision-making authority for their institutions they may represent their institutions on the Board. However, the organizational structure puts scientists in roles that capitalize on their greatest strengths, namely, designing and implementing the system.

## GoMOOS, Inc.



The so-called Science Team, chaired by the GoMOOS Chief Scientist, comprises a collection of research scientists under contract to GoMOOS. To date, the science team has implemented and operated the entire technical program, and they are documenting those aspects of the system that might be deemed "operational" in the foreseeable future. Future vendors for operations may expand to include outside contractors, other institutional entities, or federal agencies. In either case, GoMOOS will keep a core set of



scientists involved in the technical program to provide expert high-level oversight where appropriate.

The Chief Executive Officer (CEO) of GoMOOS--a scientist devoted to running the organization--reports to a Board of Directors. The CEO and Chief Scientist work with the Science Team to create budget recommendations. These recommendations are subject to final approval by the Board.

GoMOOS headquarters maintains a small staff, with the bulk of the operational program historically being implemented under contract to member institutions. Two key activities remain the responsibility of GoMOOS headquarters: data management and information-product development.

For data management, GoMOOS has a product manager and technical staff who develop and maintain a centralized database that coordinates and archives data and data products from the various components of the technical program. The data management system assures that the research quality data retain their value long into the future for all potential users. A single centralized database for the organization holds all the information relating to the technical program so that any user knows not only what kind of data was collected, but also how it was collected and how it was processed. This kind of data documentation becomes especially important with pre-operational activities for which data collection standards have yet to be created. In fact, the GoMOOS science team is creating the standards for unprecedented continuous buoy measurements of environmental health including dissolved oxygen, chlorophyll, and nutrients.

For the second key activity, namely, development and dissemination of useful information, GoMOOS has a policy and planning director. The associated responsibilities collectively assure that the system is being used effectively outside the research community. This requires two basic ingredients: (1) an understanding of the needs of users in the Gulf of Maine developed through Board interactions and ongoing market research activities coordinated by GoMOOS headquarters, and (2) the judgment and skills of the Science Team in creating a system that can best meet those needs. Information development is an ongoing process within GoMOOS.

GoMOOS has defined two external groups of experts to provide expert advice and review to assure that GoMOOS is on track with the broader Ocean.US mission: the Board of Visitors and the Science Advisory Board.

The Science Advisory Board (SAB) provides technical expertise of an advisory basis. The SAB includes respected scientists from outside GoMOOS who are experts in major disciplines of the technical program. The SAB provides external advisors for the Chief Scientist. The SAB also assures that GoMOOS remains connected with the larger scientific community. GoMOOS plans to broaden the current membership of the SAB to include experts in operational oceanography and meteorology from federal agencies such as NOAA, the Navy (ONR) and other NOPP agencies, as appropriate.



The Board of Visitors (BoV) will comprise representatives from operational agencies such as the Navy and NOAA, representatives from the user community, and individuals from the Science Advisory Board. Functions of the BoV include:

- Annual audit of all aspects of GoMOOS,
- Reviewing recommendations from the Chief Scientist and Science Team for new technologies, strategic directions, etc.,
- Advising the CEO and Board on functional needs of the organization, and
- Reviewing potential conflicts of interest.
- GoMOOS will look to Ocean.US to help define these individuals so that they may perform the same function for all other regional systems.

This probably is not the only viable institutional model for a regional coastal ocean observing system, but it fits the circumstances of the Gulf of Maine, with the effect of garnering widespread good will and encouragement, and increasing public awareness of the benefits of ocean observing. As a cooperative utility, the organization has filled a void. Indications are that others in the U.S. are looking at this model with interest.

### *Membership*

Membership in GoMOOS is open to any institution interested in supporting GoMOOS. All members pay annual dues, which are calculated on a sliding scale, based on the institution's marine revenues.. GoMOOS membership is now over 30, and continues to grow. Membership includes a diverse group of research institutions, fishermen associations, non-profits, government agencies and private companies. Current membership includes:

- Private Companies and Industry Groups

Bath Iron Works, James W. Sewall Company, Penobscot Bay & River Pilots Association, Portland Pipe Line Corporation, Saint John Marine Pilots, Saint John Port Authority, Atlantic Pilotage Authority, Eastport Port Authority, Federal Marine Terminals, Maine Lobstermen's Association, Satlantic Incorporated

- Research Institutions

Bedford Institute of Oceanography - Fisheries & Oceans, Bigelow Laboratory for Ocean Sciences, Bowdoin College, Dalhousie University, Gulf of Maine Program - Census of Marine Life, Maine Maritime Academy, Rutgers University - Institute of Marine and Coastal Sciences, University of Maine, University of Massachusetts - Dartmouth, University of New England, University of New Hampshire, University of Rhode Island, Woods Hole Oceanographic Institution

- Government Agencies

Maine Department of Marine Resources, Maine Science & Technology Foundation, Maine State Planning Office, Massachusetts Office of Coastal Zone Management, Massachusetts Water Resources Authority, Stellwagen Bank National Marine Sanctuary

- Non-Profit Organizations

Gulf of Maine Aquarium, Island Institute, New England Aquarium,

### *GoMOOS Headquarters*

Philip Bogden, former academic research oceanographer, was hired at the Chief Executive Officer in February 2002, to manage and oversee the organization. An office

was established in Portland to oversee and manage partner contracts, Board relations, membership development, user outreach, website design and data management.

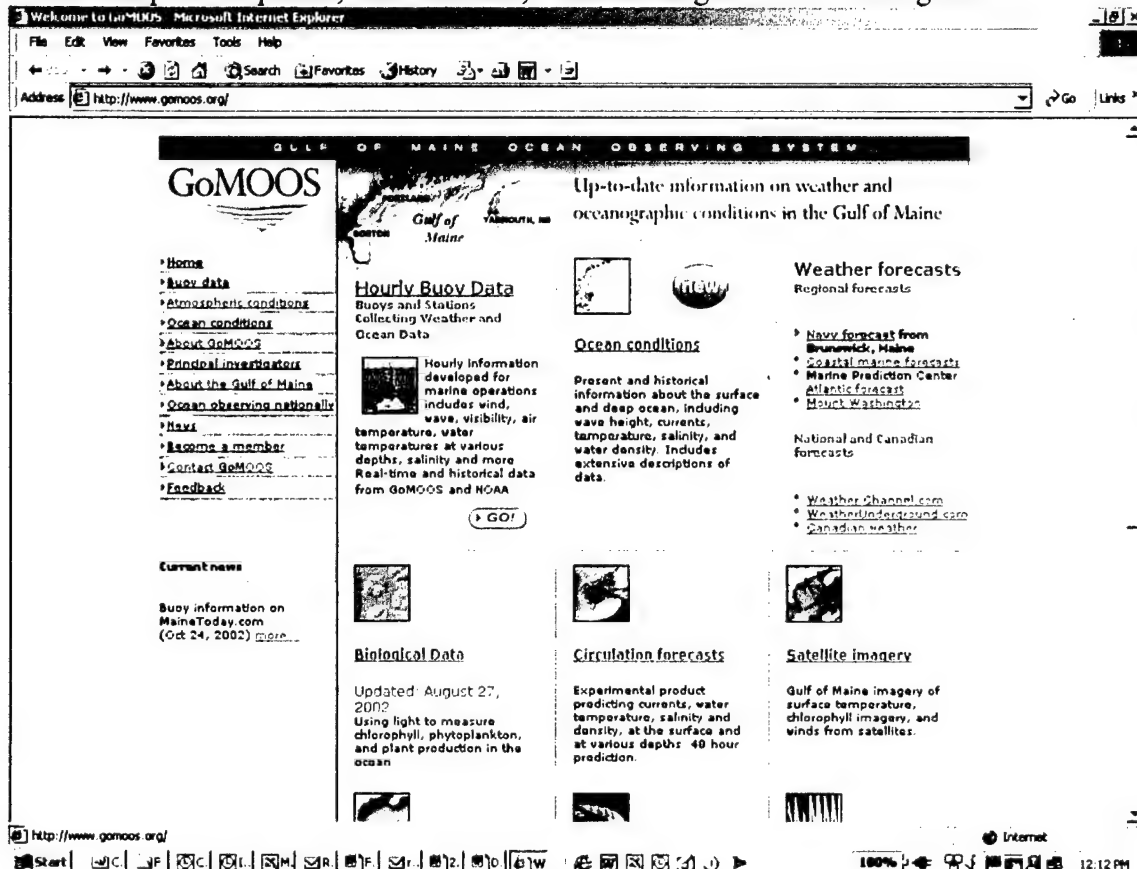


Figure 1: GoMOOS Home Page

### Website

GoMOOS's primary interface to the world is through the Internet. For a year and half, real-time data on the atmospheric and oceanographic conditions have been available on at [www.gomoos.org](http://www.gomoos.org).

The website changes and expands continually with development of new information products as GoMOOS responds to user needs. The initial web design (see Figures above and below), incorporated the ideas and suggestions gleaned from a "discovery" process with mariners (shippers, fishermen, recreational boater, etc). The discovery process is a standard market-research tool for product development, in this case applied to web development. During a discovery process users are asked questions about how they make decisions, the kinds of technology that they use, and the kinds of information that they use, day to day. They are not asked direct questions about website design. For the first website release, GoMOOS interviewed over a dozen fishermen, shippers, harbor pilots and boaters as part of the discovery process, and a similar amount during prototype testing. Key elements in the website design included the need for simple graphics that load easily on dial-up connections, the importance of weather information and the need for information when at sea, browser compatibility and the need to avoid browser plug-ins and special software downloads.

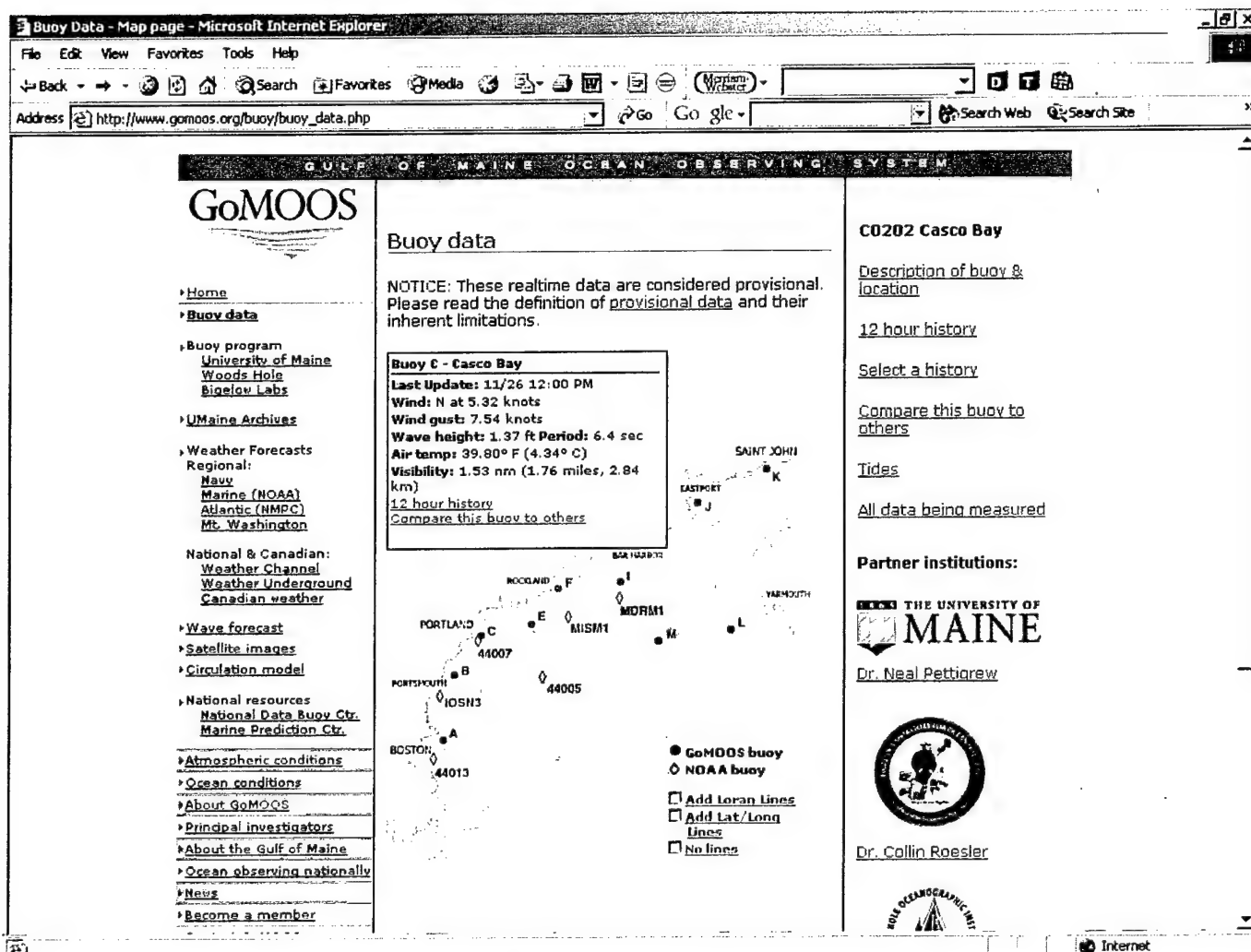


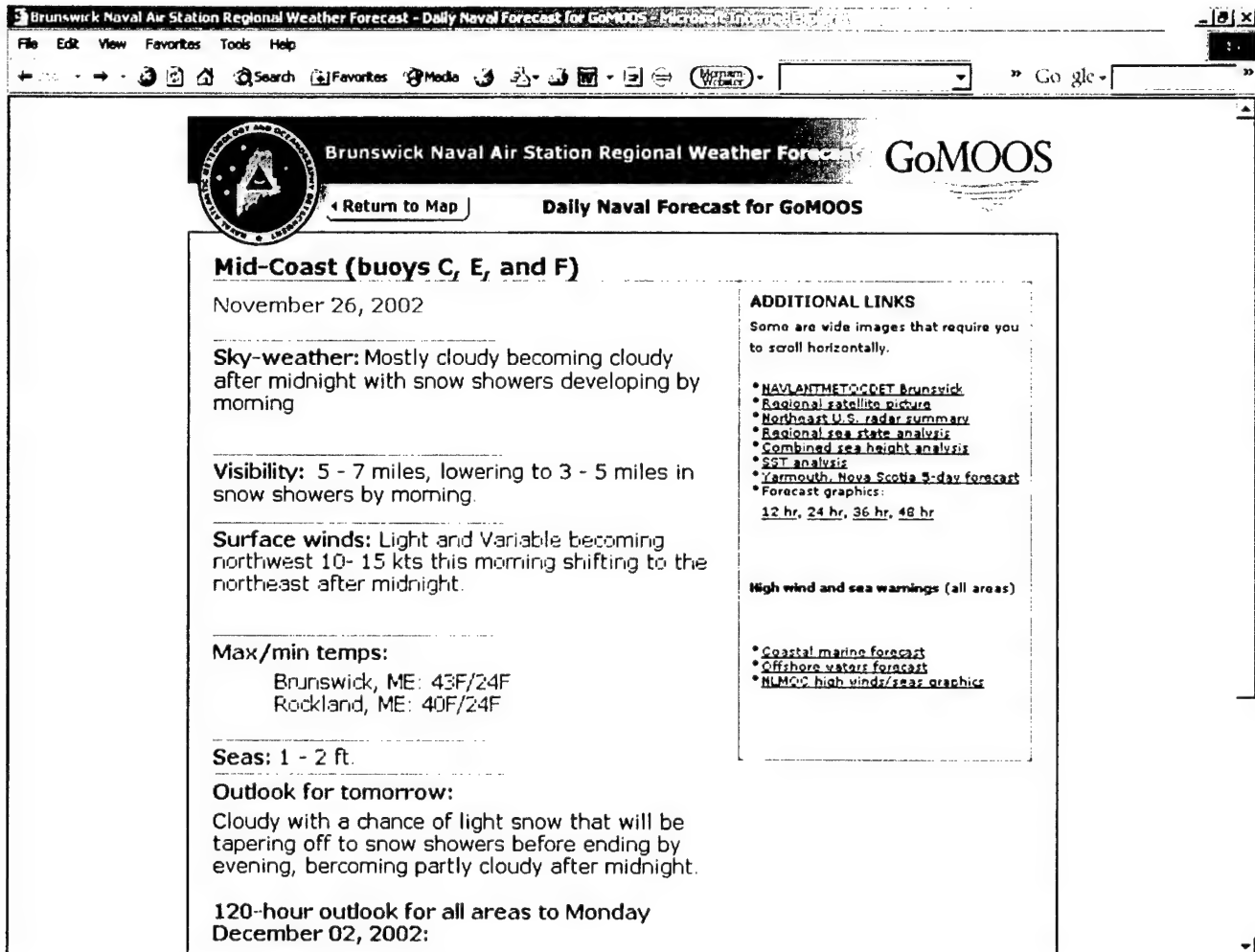
Figure 2. GoMOOS Buoy Data page created for mariners

The interface for real-time buoy data (above) emphasized the mariners' needs for present conditions. They wanted quick access to multiple-buoy comparisons, charts of the 12-hour history, navigational charts showing the buoy locations, etc. All these are in easy reach from the "buoy data" page at gomoos.org.

Recent additions to the website are following a thematic approach. The objective is a theme-based catalog of GoMOOS data products, which will serve as the basis for continued product development. The catalog presents a comprehensive look at specific topics such as oceanographic conditions, atmospheric conditions, environmental health, and water quality. The oceanographic and atmospheric conditions products were launched in September 2002, combining remotely sensed data with in situ measurements to provide users with comprehensive look at the GoMOOS information on the theme. Biological data and wave modeling is planned for December; water quality will follow in February.

### *Navy Partnership*

GoMOOS established an MOA with the U.S. Navy for three activities: (1) site-specific weather forecasts in the Gulf of Maine in collaboration with Brunswick Naval Air Station, (2) wave-forecast model development with NAVO in Stennis Mississippi, and (3) circulation modeling with Fleet Numerical in Monterey California. The site-specific weather forecast pages (see below) are perhaps the most popular. Mariners have commented that the Navy forecasts are by far the most accurate for the region. Naval forecasters use a variety of information sources for their forecasts, GoMOOS data among them.



**Figure 3: Brunswick Naval Air Station site-specific GoMOOS weather forecast**

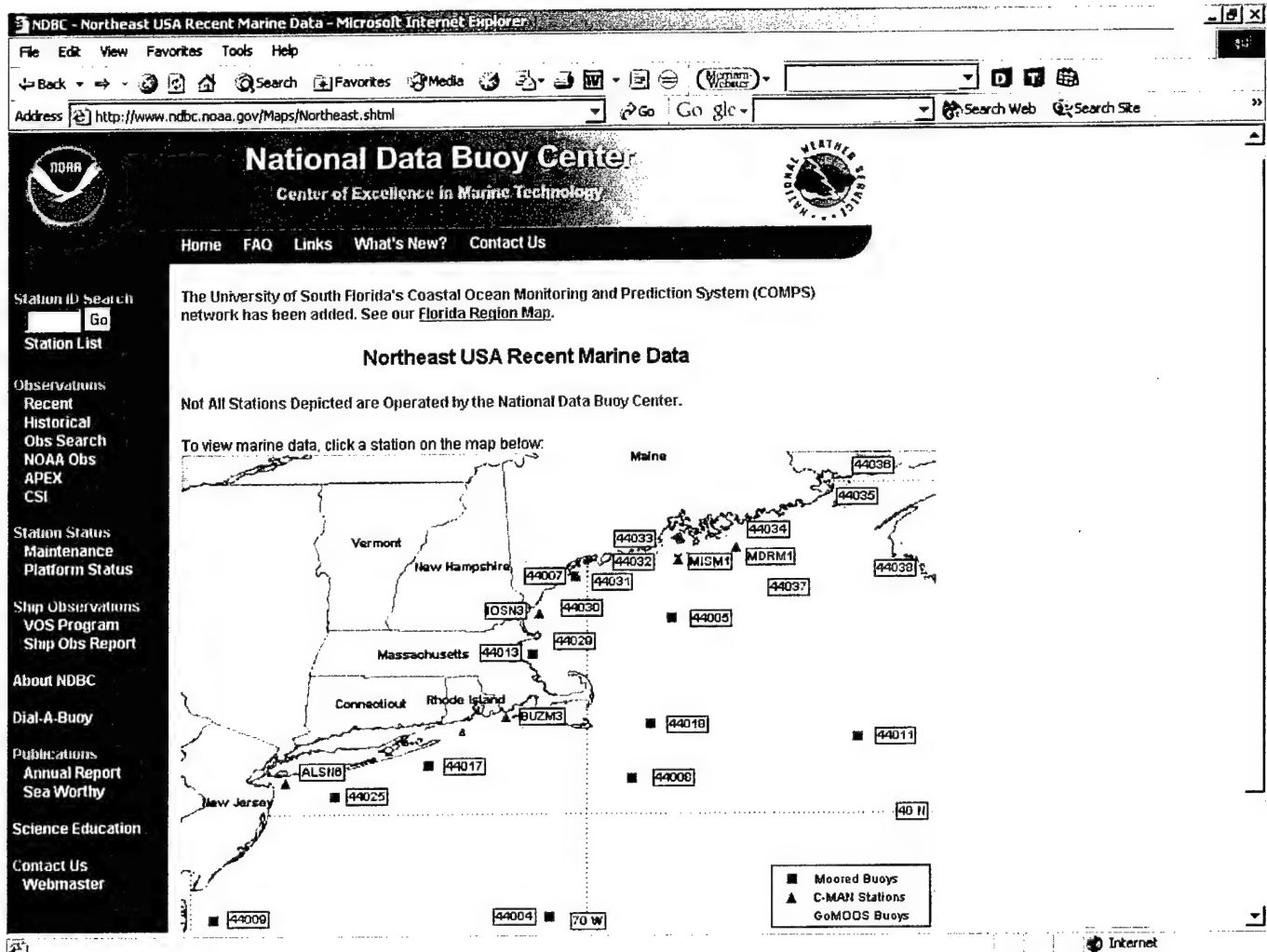
### *NOAA Partnership*

GoMOOS has been working locally with the Weather Forecast Offices to make data available for their use. As a consequence, GoMOOS data became part of the regular NOAA Maine Weather Radio broadcasts in the New England region.

GoMOOS also established a partnership with NOAA's National Data Buoy Center (NDBC), which led to incorporation of GoMOOS data into the National Weather Service

forecasts and the NDBC dial-a-buoy service. Dial-a-buoy has been especially popular with professional mariners who need access to the information when they're at sea and away from their computers. This service has been well received and the GoMOOS-distributed dial-a-buoy instruction cards are now in their second printing.

With GoMOOS data part of the NWS, local television weather forecasters were able to start getting forecast products that included GoMOOS data from their professional weather providers. As a result, GoMOOS data started becoming a regular feature on the local television in the summer of 2003.



Weather in Maine Today.com - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Forward Stop Search Favorites History

Address http://weather.maine.today.com/ Go Links

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**WEATHER**  
Wednesday November 20, 2002

FORECASTS PROVIDED BY:  
WMTW METEOROLOGISTS  
RUEB HUALEY AND  
GRAY STABLEY

**TODAY'S FORECAST**

Hi 46 F, Lo 33 F  
Coast: Partly to mostly sunny  
skies. Light southwest winds at  
10-15 mph.

Inland: Partly if not mostly sunny skies. Winds  
southwest at 10-15 mph.

**EXTENDED FORECAST**

**Thursday:** Hi 45 F, Lo 37 F  
Morning sun gives way to  
increasing afternoon clouds.  
Winds become southeast at 5-15  
mph.

**Friday:** Hi 41 F, Lo 35 F  
Cloudy with periods of light rain or  
showers. Winds east-northeast at  
10-15 mph.

**Saturday:** Hi 43 F, Lo 29 F  
Clouds with some limited  
sunshine. Showers or flurries

**Storm Closings**  
SPONSORED BY  
**Central Maine Power**

When bad weather hits Maine, we  
will post school and business  
cancellations, delays, parking bans  
and the latest local forecast. See  
the Storm Closings pages for  
details.  
Produced in partnership with  
**News 8 WMTW**

on the **Ocean**

**Current conditions on  
CASCO BAY**  
Last update: 11/20 11:00 AM  
Wind: 3.5 knots WSW  
Air temp: 43 F  
Water temp: 48 F  
Visibility: 1.6 miles

**GoMOOS**

Visit the GoMOOS Web site for  
current conditions at other Gulf  
of Maine buoys.

**TODAY'S PORTLAND TIDES**  
High: 10:55 a.m. 9.70 ft, 11:29  
p.m. 8.69 ft  
Low: 4:45 a.m. 1.04 ft, 5:17  
p.m. 0.13 ft

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Figure 5: Portland Press Herald website weather pages with GoMOOS data presentation

GoMOOS has appeared on several different Maine Public Radio segments, and will appear on public television soon. QUEST is an educational science show on Maine Public Television. In January, they will air a show on remote sensing which includes a segment on GoMOOS. As a companion to the television show, the producers developed a high school curriculum. The curriculum focuses on the GoMOOS section of the show and instructs teachers how to access GoMOOS information from the web to use in their classrooms.

### *The National Scene*

And GoMOOS contributes to work with Ocean.US, the US GOOS SC, the U.S. Commission on Ocean Policy, and other nascent regional systems to help implement the national federation of regional ocean observing systems as envisioned by the National Ocean Research Leadership Council and its program offices.

## Data and Information Management

*Kate Beard, University of Maine*

*Philip Bogden, CEO, GoMOOS*

### *Data and Information Management Objectives*

The originally proposed GoMOOS information management system had several operational objectives, including:

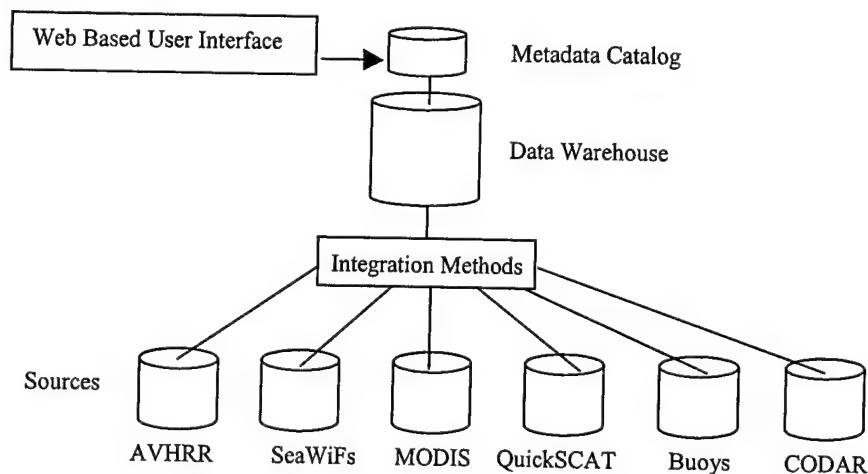
- I. Design that serves both the immediate and future missions of Ocean Observing Systems,
- II. Flexible and modular structure that is compatible with current systems and amenable to evolution as information technology changes,
- III. Capability to provide users with search and discovery capabilities, and to provide seamless access to any information within the system, and
- IV. Capability to integrate with other Ocean Observing Systems, with historical data archives for the Gulf of Maine, and a range of heterogeneous distributed sources.

These objectives describe the system that has been put into place to date. The objectives have been augmented in one important respect:

- V. The system assures that the research quality data will retain their value with a centralized database that holds all the information relating to the data acquisition system (buoy program) allowing any user to know not only what kind of data were collected and their values, but also how they were collected and how they were processed.

### *System architecture and data model development*

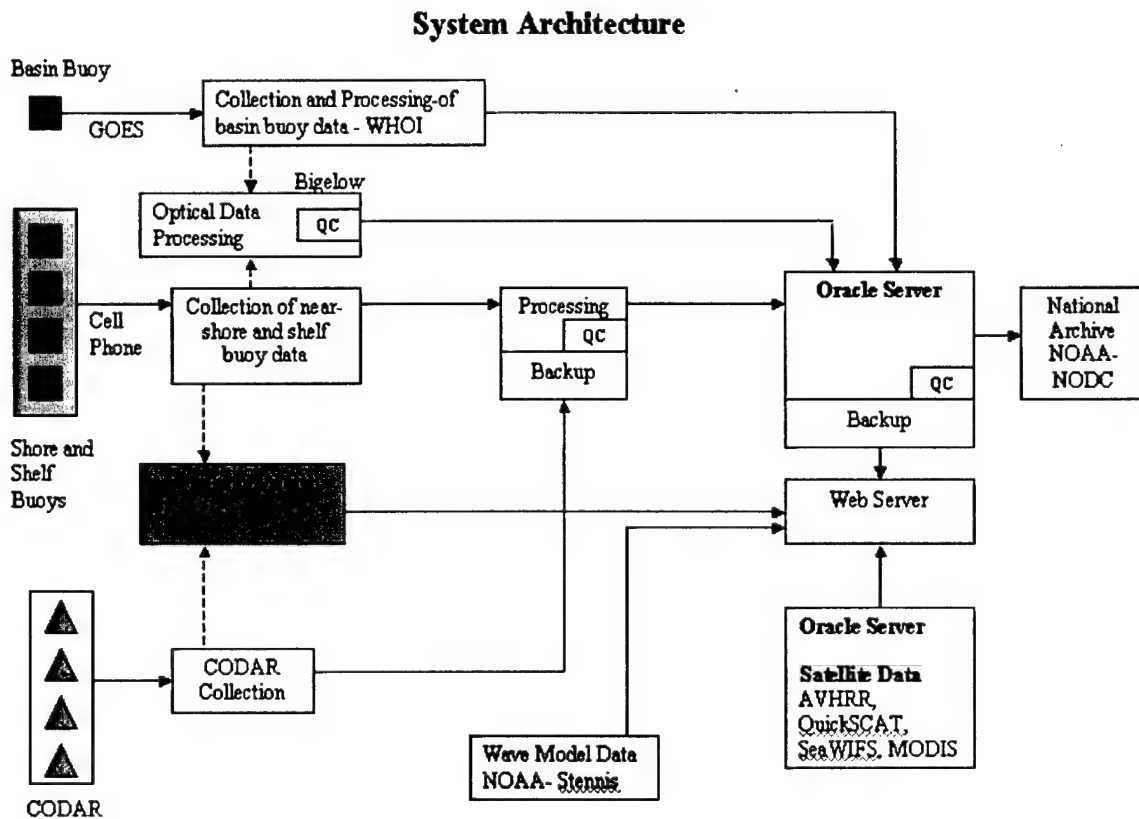
The initial proposal indicated that GoMOOS data would be managed through a data warehouse environment that would support dissemination of GoMOOS data and products over the Internet. Figure 1 indicated the initial proposed system architecture diagram.



**Figure 6: Initially proposed system architecture**



Over the course of several staff meetings and fact-finding activities, the proposed system architecture was refined to account for the various data streams, their origins, archive locations and data quality protocols. A schematic of the overall system architecture is shown in Figure 7. This iteration reflected a more complete understanding of the data collection processes and addressed the reality of different data archives for different data streams. Satellite data and circulation model outputs for example were being generated and maintained in separate archives. The outcome is essentially one of less ability to perform integrated queries across the various data sources. For example under this architecture a request to retrieve all GoMOOS data collected for the week of July 15 becomes a more difficult task to accomplish. Subsequently, the system architecture has been further refined culminating in a system specification adopted and implemented as the current operational system.



**Figure 7. Refined system architecture with detailed data flow**

The initial proposal indicated a metadata catalog that would provide a frontline interface for GoMOOS users. This metadata catalog was intended to contain summaries of the data contained in the warehouse including descriptions for data sets or observations indicating times, spatial locations, and depths at which data were being collected. A comprehensive summary of the overall composition of the GoMOOS archive is still an outstanding goal.

Comprehensive metadata development and maintenance for each individual data source was discussed at length. An initial data and metadata schema was developed collaboratively among the staff working under each of the GoMOOS component parts. Staff met once a week for a period of seven months from January 2000 to July 2000 to discuss data characteristics, metadata requirements for each data stream, quality control checks and their placement in the data processing stream and system maintenance. Metadata reports compliant with the FGDC Content Standard for Geospatial Metadata were developed for each data stream with the exception of the CODAR data: e.g. buoy data, satellite data and model data.

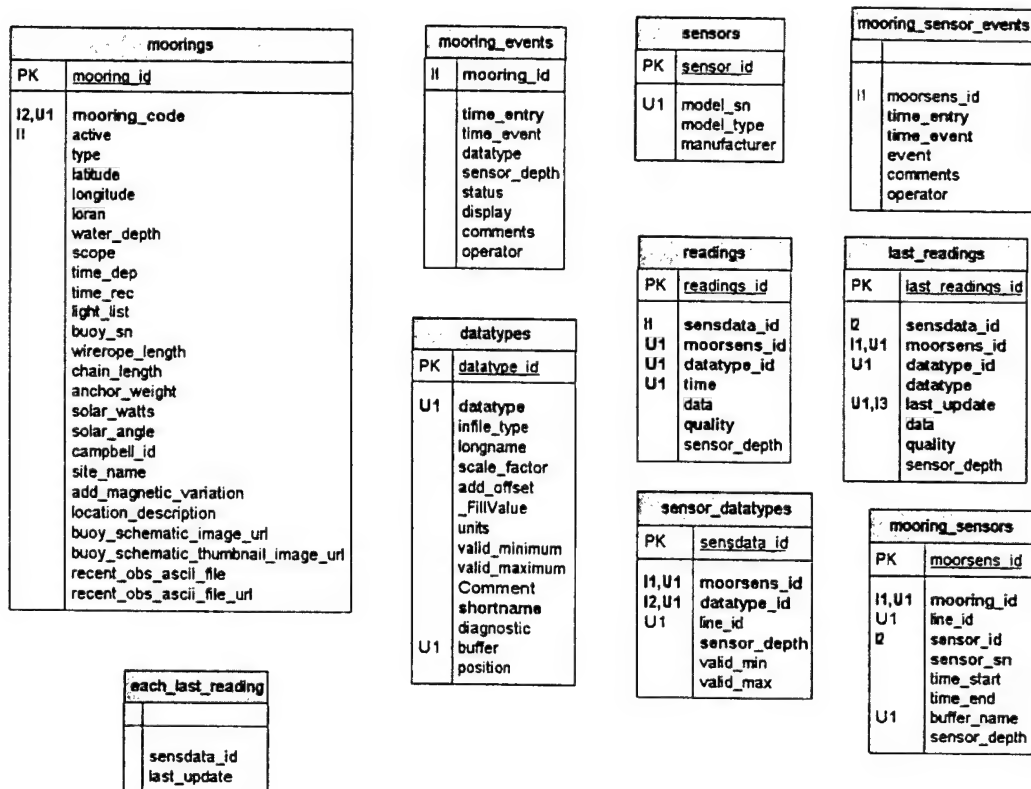
Several iterations of the combined metadata, data model evolved over the course of these staff meetings. The prototype schema for data and metadata and the data quality management strategies were passed on to the GoMOOS operations group once a programmer and project manager were brought on board. A final data model was agreed on and a RFP for database implementation was issued in May 2002.

The initial implementation suggested use of an Oracle database management system. Given the need to reduce costs and reliance on commercial products, several open source options were considered. MySQL was selected as a cost effective short-term alternative to an Oracle database implementation. The data model is likely to evolve as it is tested, as more data and products are generated and as the functionality of the web application expands.

### *The Operational System*

The original proposal identified the following specific design criteria:

1. Client/server architecture that manages data through a data warehouse that supports the dissemination of GoMOOS data and products over the Internet.
2. Integration step where data are structured, normalized, checked for inconsistencies and derived products created. The warehouse itself must be capable of storing heterogeneous data types including structured data plus text, imagery, video, and potentially audio.
3. Metadata catalog to provide a frontline interface to the user, including summaries of the data contained in the warehouse, brief entries for data sets or observations that note times, spatial locations, and depths. Additionally the catalog may include thumbnail versions of images, histograms, time series plots, model descriptions and images of model results. The catalog thus contains abstract representations of the full data sets contained in the warehouse.
4. The development of the data warehouse will involve development of warehouse services and metadata services. Warehouse services will be built on top of a commercial database system that supports spatial and temporal data types and indexing over these data types.
5. Data warehouse server that supports easy loading of new data sets, multiple indexing over the data sets and summaries of new data that can be passed up to the metadata catalog. The warehouse server must support potentially large numbers of users with optimal query performance across a range of query types.



**Figure 8: Schema for the 2nd generation GoMOOS database.**

Progress on the GoMOOS system will be reviewed in relation to these proposed criteria.

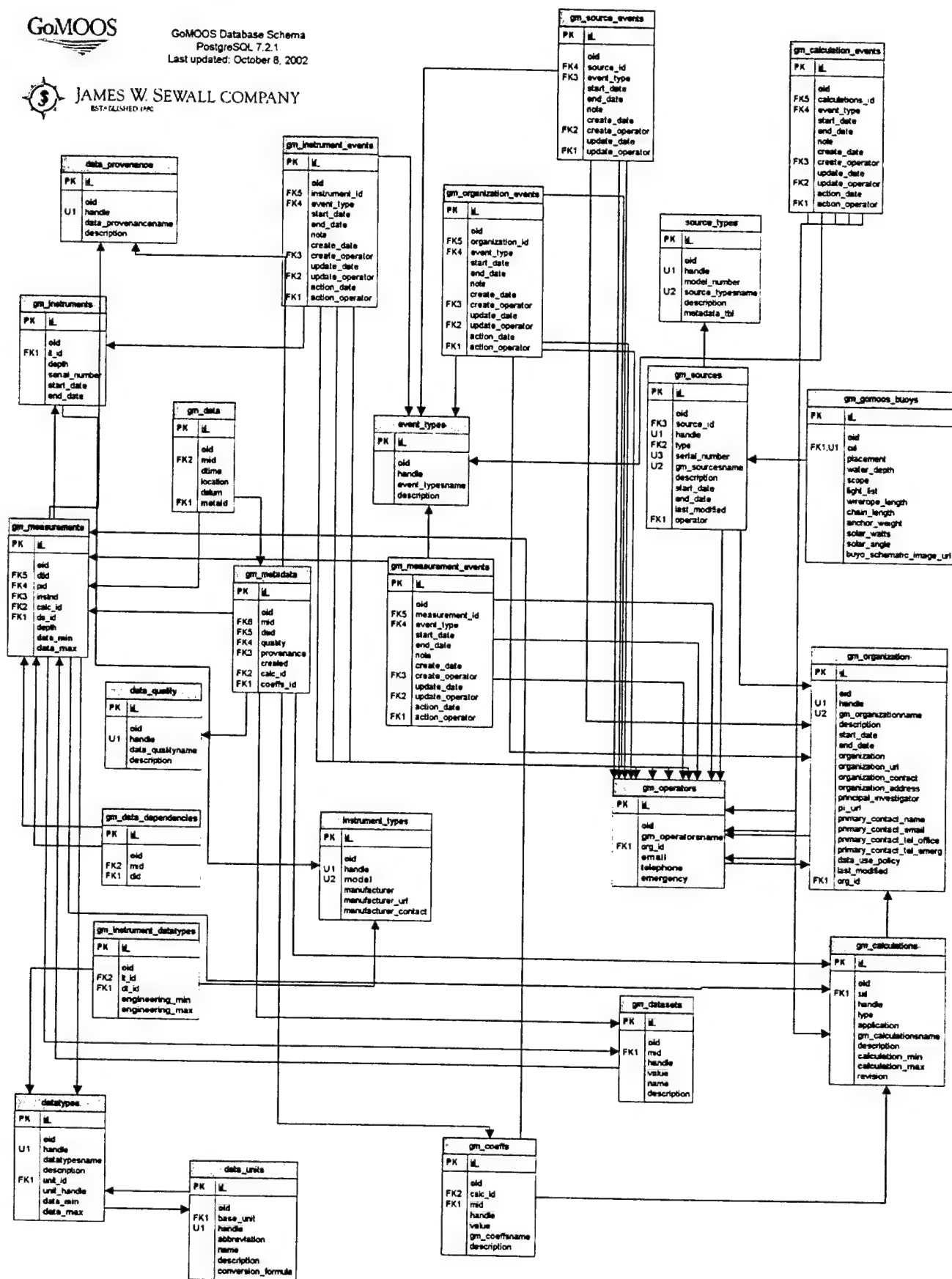
The data management system uses criterion #1—a client/server architecture—for getting from data sources to the users. Criterion #2—data-integrity checking—has been partly implemented. The underlying objective is to store buoy data in the most “raw” form available and then maintain the software that can be used to create data products from that raw data. This way, any post-processing, calibration, or re-calibration can be documented in the software, which is stored as metadata. This means recalibrated values can be easily recomputed when the new calibration coefficients are determined. This strategy accommodates both “24/7” needs to get data out quickly, and long-term research goals to get the most accurate values. The latter often requires post-hoc analysis due to recalibration of instruments when they return from sea, etc. As a result, data presented in real-time need not be the same as data archived in the database for later use. Either way, the database provides a detailed record of everything done to obtain the available data.

Criterion #3—the metadata catalog—is nearing completion for buoy data. A new 3rd database schema has been created to accommodate the metadata for other data types. Criterion #4—metadata services built on top of a commercial database for use with spatial data—has not been adopted, at least not yet. As mentioned above, open-source (freely available) database software serves our purposes for the moment, and those purposes do not include spatial data types used by many commercial products. The

primary impediment to moving to the existing system to commercially available software (such as Oracle) will be the cost of software licenses. The presently used 2<sup>nd</sup> generation data schema (implemented on MySQL and PostgreSQL) is database independent.

Criterion 5—server scalability and efficiency—has been implemented in the current 2<sup>nd</sup> generation database that serves [www.gomoos.org](http://www.gomoos.org). The schema for this database (see figure) is presented above. This database developed from the requirements for storing information in the buoy program. The tables use a legacy naming system as a result. But the data schema can accommodate any kind of scalar time-series data obtained at a fixed location. New data types, instrument types, locations, etc., can be added without the need for an additional table in true relational database style. The schema easily accommodates queries by spatial location, time, data type, mooring, instrument type, etc. We use the schema to store and re-display data from NOAA buoys, and C-MAN stations. These 10 tables can accommodate any kind of instrument in the moored buoy array and unlimited data types.

The 2<sup>nd</sup> generation database cannot readily accommodate fields of values, as might be associated with numerical models, satellite AVHRR, CODAR etc. Consequently, the 3<sup>rd</sup> generation database will be needed serve spatial data, multi-dimensional time series (e.g., CODAR), images, etc. The schema for such a database (shown below) has been designed and implemented, but it remains to be populated with real data and incorporated into the data management system.



### Figure 9: The 3rd Generation Data Schema

*Client Services: The Technology of Turning Data into Information*

Progress on the technological infrastructure to create information products will be reviewed in relation to the requirements listed in the original GoMOOS proposal and reproduced here:

- A. Viewing of now-time conditions: Graphical displays of near real time conditions for measured variables: sea surface temperature, wind speed, ocean color, surface currents, scatterometer winds, and buoy data will be made available. Users should be able to easily navigate and request the variables of their choice and zoom and pan functionality will be supported for these displays.
- B. For mariners, or others without access to computers and the Internet, the latest buoy data should be available via phone from a system akin to the NDBC's Dial-A-Buoy system. The buoys and data types will be selectable via a menu and a computerized voice will read a text message with the latest data values.
- C. Downloading of now-time data with the Distributed Oceanographic Data System (DODS). DODS is a client-server system that uses http as the low-level communication protocol.
- D. Searching the archive: In addition to supporting display and download of now-time data, users should have access to the GoMOOS archive through flexible and efficient search and retrieval. Search functionality should allow for search over the spatial dimension (e.g., near shore, Massachusetts Bay, a region specified in latitude and longitude, depth, etc.), the temporal dimension (e.g., data from last year, from last January, from last summer, etc.) and topical criteria (e.g., sea surface temperature, currents, dissolved oxygen).
- E. Browsing the archive: Users need the capability to quickly browse the archive for information of interest. Browsing will be supported by summary information on the archive contents. Thumbnail versions of images stored in the metadata catalog will be accessible to users to quickly check for presence of features of interest or presence of cloud cover.
- F. The GUI component will consist of a web-based front end developed in Java for platform independence. The Java front end will provide intuitive access to the warehouse services that support query, browse and retrieval of information from the archive.

Services A and B—viewing of real-time conditions and dial-a-buoy—have been implemented at [www.gomoos.org](http://www.gomoos.org). Dial-a-buoy was obtained in collaboration with NOAA's National Data Buoy Center (NDBC). As a result of the NDBC collaboration, GoMOOS data are ingested into the National Weather Services AWIPS system, so GoMOOS data have become part of the national forecast system. Moreover, commercial weather providers, such as WSI Inc., are creating data products for forecasters such as Dave Santoro, the weather forecaster for a local television station in Portland, Maine. And GoMOOS buoy data have become regular components of NOAA's weather radio broadcasts.

We have yet to completely implement Service C—DODS access—to the GoMOOS database. Although there was one point where the DODS server was working, the newly renamed OPeNDAP project (formerly DODS) doesn't have a completely functional

database interface. This is an ongoing project. Nevertheless, many GoMOOS scientists are independently serving data through the NetCDF interface.

Service D—metadata search capability—was built into the 2<sup>nd</sup> generation database schema presently in use at [www.gomoos.org](http://www.gomoos.org). All that remains to fully implement D is creation of a user-friendly interface. Preliminary work on this interface is nearing completion. We view the notion of “useable” interfaces as an ongoing activity that requires interactions with users.

Service E—browsing interface—ties in closely with Service D. With regard to Service F—Java for platform independence—we use platform-independent software (the stated advantage of Java) as a matter of course and rely heavily on Perl and PHP, but we use relatively little Java.

#### *Client Services: Transforming Data into Information for Users*

In the fall of 2001, GoMOOS began the first element of a four-pronged strategy developing useful information products. A 6-month-long process led to the implementation of the real-time buoy data pages at [www.gomoos.org](http://www.gomoos.org). The entirely new web site was designed with mariners in mind, and involved a series of interviews with fishermen, harbor pilots, and recreational boaters. This “market research” and “discovery” process, along with extensive prototype testing, resulted in the user interface for real-time data that can still be found at the GoMOOS website. The interface has been linked to some private web sites, including the weather pages at [www.mainetoday.com](http://www.mainetoday.com) (the Portland daily newspaper), and the buoy-data pages at [www.maineharbors.com](http://www.maineharbors.com) (used by recreational boaters).

Under our first ONR grant, we also began a yearlong effort to develop a web-based thematic and annotated catalog of GoMOOS data products. The strategy is to convert GoMOOS data into data products, provide some context for those data products, and then use those products as the basis for market-based information-product development. The first set of deliverables can be found by clicking on the “atmospheric conditions” and “oceanic conditions” pages at [www.gomoos.org](http://www.gomoos.org). This catalog builds on ideas that came out of the January 2002 Board of Directors retreat. There is no specific target audience for these products other than educated and interested non-scientists. This project will produce additional themes in the near future, including “wave predictions,” “ocean biology” and “environmental health.”

We have been working with the resource managers on our Board of Directors to identify specific information products that will serve their needs. The first step in this effort involved an overview meeting between Board Members and some of the GoMOOS PIs. The next stage will involve smaller focus groups that will identify some special projects or web-development activities that can be implemented with existing resources for information-product development. This will be an ongoing activity that should bear fruit in the next year and beyond.



Educators are the second user group we've targeted for information product development in the next year. Our plan is to involve our own staff and contracts under the "accepted vendor" model in our web-development activities to perform the user discovery and web-development activities for these users. Target date for this effort: Spring of 2003.

## **Buoy and CODAR Program**

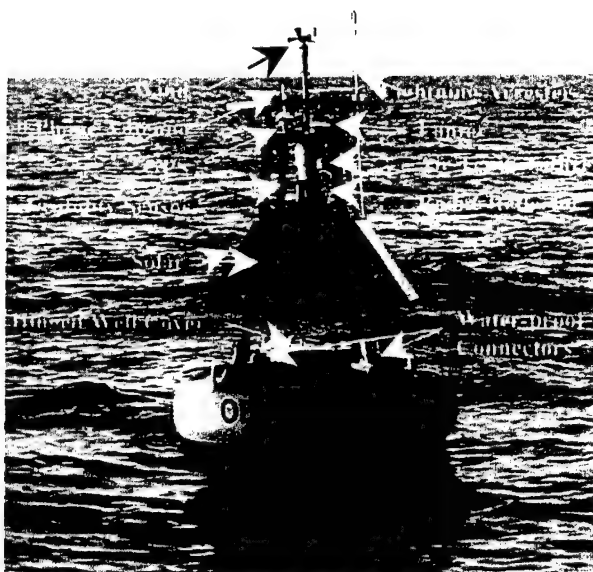
*Neal R Pettigrew, Chief Scientist, University of Maine*

### *Buoy Design and Fabrication*

The central element of GoMOOS is the Ocean Data Acquisition Systems (ODAS) moored telemetering buoy array. The buoy array provides the platforms for the present and future suite of sensors that furnish the long-term, real-time data series that form the basis of the *in situ* physical, optical and bio-optical ocean observing in the Gulf of Maine. The design and production of these buoys, and this array, was the primary task of GoMOOS and the University of Maine's Physical Oceanography Group (PHOG) during the implementation phase of GoMOOS.

PHOG has been designing and building ODAS systems designed specifically for the GOM environment since 1993. Since 1998, these buoys have been solar-powered and have had real-time data telemetering capability. The primary design tasks for the GoMOOS effort was to modify the buoy hull design so that the buoy could withstand the rigors of year-round offshore deployments in the Gulf of Maine, and to design a telemetry/data system that would provide for future sensor additions and maximum flexibility in sensor attachment/repositioning.

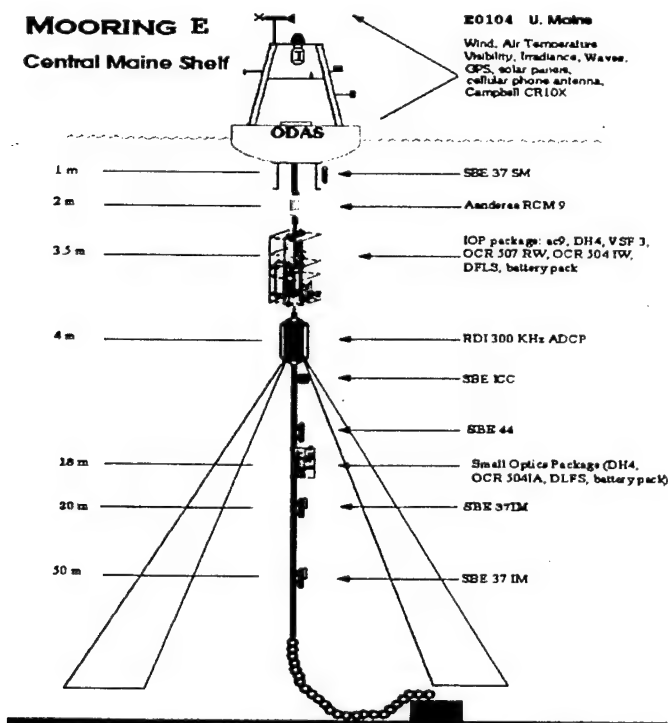
The design process started by combining telemetering and electronic characteristics of the PHOG buoy with some of the mechanical characteristics a buoy designed by Dr. J D Irish of the Applied Ocean Physics and Engineering Department at the Woods Hole Oceanographic Institution. The WHOI buoy had successfully withstood the rigors of winter on Georges Bank. Since icing of the superstructure of ships and buoys in the Gulf of Maine is often much more severe on the shelf than on the bank, the buoy design was modified to increase its righting moment and reserve buoyancy. The criterion used was that the buoy, without benefit of its subsurface load, be stable with 300 lbs of ice on its superstructure. As a by-product, the buoy will also support a technician on its deck so that minor repairs can be made while it is deployed. Finally the buoy was designed to be unsinkable. This was achieved by balancing its sources of flotation between the instrument well and the closed-cell foam flotation collar. The foam flotation is effective even if the buoy is pierced, and the aluminum instrument well provides enough backup buoyancy to assure that even if the buoy is dragged down to a depth of 100 m, and the foam flotation compress, it will rise again to the surface where the foam will decompress.



The buoy superstructure carries a suite of meteorological sensors including wind speed and direction, air temperature, and visibility as well as the sea keeping components such as radar reflectors, lightning rod, solar panels, and antennas for the GPS and telemetry system. The data logger, buoy electronic and power systems are in the buoy well.

Data from the subsurface sensors are transmitted in two ways. Near-surface sensors are hard-wired to the water-proof connectors to the buoy data system, while deep instruments telemeter their data streams via

inductive modem technology. This technology allows data from up to 100 locations beneath the buoy to send data directly up the mooring cable with requiring direct electrical connection. This system, designed and marketed by Sea Bird Instruments Inc., is based on transformer technology, and inductively couples the sensors with the jacketed mooring cable. Sensors deployment depths may be changed at will, damaged sensors replaced, or sensors added without removing the buoy and mooring from the water.



A schematic diagram of a GoMOOS mooring is shown at left. The example shown is one of the Central shelf moorings that are the most heavily instrumented. All the sensors between the surface and 4 m depth are electrically hard-wired to the ODAS. The deeper sensors and sensor packages send their data to the buoy data logger via the inductive modem technology.

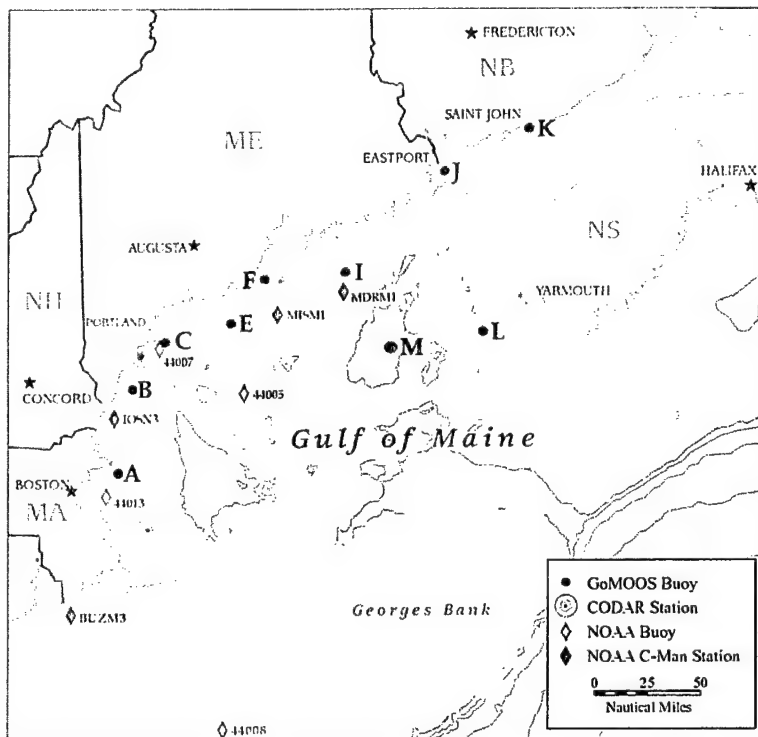
Near-surface currents are measured at 2 m using an Aanderaa RCM 9 Doppler current meter. Since these CM's use acoustic Doppler technology, they are immune to the sometimes severe bio-fouling that occurs in the GOM at many locations. After a 6-month

deployment some of the near-surface sensors are recovered with several inches of blue mussel and other growth on them. The sound propagates through the fouling with little attenuation and the measurements are unaffected. Doppler current profilers are used to measure the current from 4m down to the near bottom. These instruments act as remote sensors and also are unaffected by the "blue mussel beards" that they often display after a six-month deployment. The optical instrument packages are described in the report by Dr. Roesler, and will not be discussed here. Seabird instruments are used to measure temperature and conductivity at fixed depths (here 1m, 20m and 50 m). At some GoMOOS mooring locations the transmissometers and dissolved Oxygen sensor are couple will seabird TC sensors. A complete list of the sensors deployed at each buoy location may be found websites <http://www.gomoos.org> or <http://gyre.umeoce.maine.edu>.

The GoMOOS buoy systems have some self-monitoring capability. All the buoys and are equipped with Global Positioning System (GPS) drift detection software, leak detection hardware, and power system autocheck systems. Coupled with the cellular telephone/GOES satellite data telemetry system, the buoy checks on its own status and sends alarms if any of the parameters are out of range. These systems have proven very capable in thus far for shelf locations. Since the GOES system does not have the data throughput to handle all the data, it serves as a backup in the event that cellular connection is not achieved for a particular hour. In this event the Deep currents and optics data are not reported until the next successful cellular connection.

### *The Buoy Array*

Ten buoys locations have been occupied (most continuously) during the GoMOOS implementation phase. Buoys were deployed starting July 2001, and the entire array was initially deployed by September 2001. The GoMOOS buoy array is shown at left on the inset map as the red dots. As is evident from the map, the GoMOOS array has significantly expanded the number of locations at which meteorological and wave monitoring occur in the GOM. In particular, prior to the GoMOOS



deployment wave measurements were made only in the GOM east of NDBC buoy 44005 on Cashes ledge. Buoy winds in the eastern GOM region was similarly sparse, and these additions provided mariners, oceanographers and meteorologists alike with welcome data sources.

The originally proposed GoMOOS array plan called for buoys of the design discussed above at locations B, E, I, L and K. As a cost-savings measure, nearshore locations were to be populated with smaller less expensive buoys that would not be designed to withstand the rigors of the open GOM. As the final buoy locations were chosen however, it became clear the many of the nearshore buoys would be subject to wind, wave and current regimes that closely approached those expected in the open GOM. As a result, it was decided that locations A, C, F, and K would all be better served by full-size GoMOOS buoys. Only J, in the Cobscook Bay, was judged to be significantly sheltered waves and, to some extent, winds. On the other hand, site J was expected to experience the strongest tidal currents of all the GoMOOS buoy locations. In the final analysis, full-size GoMOOS buoys were deployed at all locations. Building the more expensive buoys was made possible through cost savings by efficient use of ship time and by using a smaller (and less expensive) ship than called for in the original proposal, cost sharing with other PhOG projects, and reduced personnel costs due to extremely high personnel motivation and productivity on part of the PhOG staff.

#### *Deployment/Recovery Rotation and Equipment Redundancy*

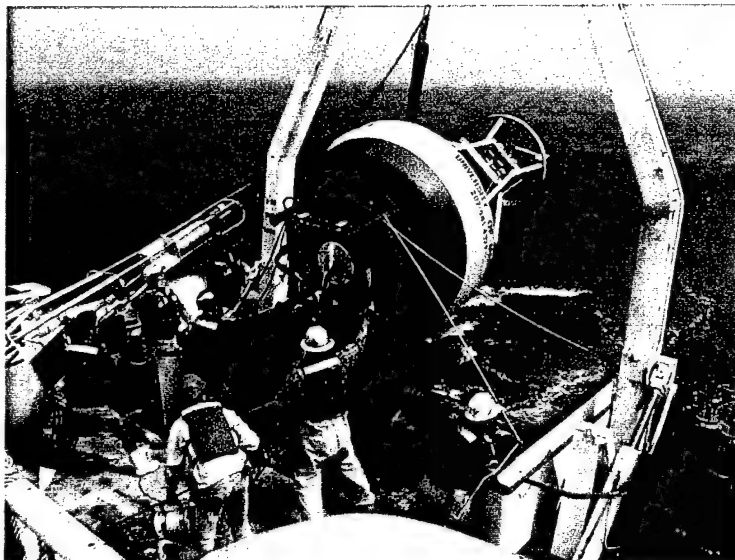
An operational decision was made to schedule service for the entire array twice per year rather than staggering the east and west maintenance that would have required four (shorter) service periods per year. The revised schedule saved approximately four man-months of effort in pre- and post- cruise preparations, and roughly 20% of the boat charter fees by reducing transit times. In order to realize these efficiencies, we needed to increase the sensor and buoy "redundancy" to approximately 100%. Thus, we could leave port with a completely prepared replacement buoy and recalibrated sensor for each of the GoMOOS buoy locations. This routine saved many days of ship time since we did not have to turn equipment around during the cruises (except for optical sensors for which funds to purchase the required units were unable to be found).

Further reduction of operational costs could be realized in the future by making sure two complete systems, plus a few spares for breakage, are available for each buoy and its complete suite of sensors. This concept is endorsed by the GoMOOS Board of Directors not only as a way to reduce costs but believe redundancy is important for an operational system. At present GoMOOS has 18 complete buoys systems with 2 more under construction.

Shipboard operations were refined throughout the implementation period. Early cruises were staffed by two scientists and three technical staff. By the end of the contract a typical deployment/recovery cruise was done with as few as two technical staff with the cooperation of the ship's crew.

### *PhOG interim website and database*

Although PhOG was not funded in its contract to provide the GoMOOS website and data archive, PhOG produced both of these crucial functions so that the real-time data were delivered within hours of the first deployments. These services were as the interim solution until the official GoMOOS website became operational some months later. The PhOG website, database, and web download and plotting capabilities are still provided to scientific users through a link from the GoMOOS.org site. Data processing and QA/QC are provided by the PhOG staff and processing software on a continuing basis.



### *Buoy system performance*

The newly designed GoMOOS buoy has proven to be a good performer during the implementation phase of the GoMOOS program. Even during the shakedown year, data returns on physical data exceeded the 70% target. Individual buoys exceeded 90% data return overall. Most of the data losses resulted from mechanical coupling problems at the upper optics package. This design flaw required the

premature recovery of three buoys at a time when their replacements had not yet been fabricated. We also had winter storm damage and vandalism at location L that resulted in poor data returns at that site. Additional ballast has added to all buoys to improve buoy performance under the extreme wave conditions observed (max significant wave height 12 m). Steps are being taken to better inform Canadian fisherman of the purpose of the buoy and to get their input on its location.

The second most significant cause of data loss was premature sensor battery failure in the surface current meters and some of the temperature/salinity packages. These problems were due to firmware problems that have been largely rectified by the manufacturers.

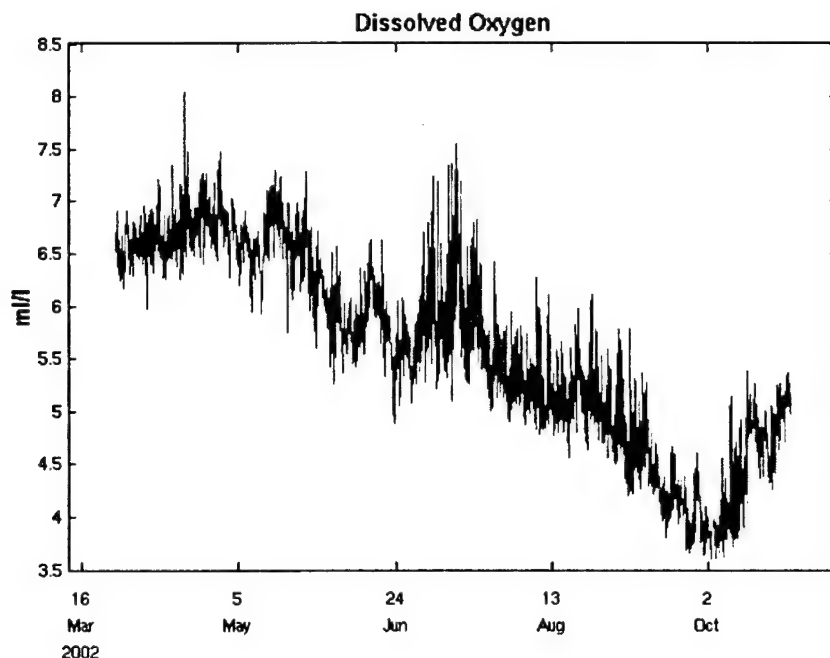
Success of the buoy optical program was below 50% for the first year of operations. These packages are an R&D effort within the buoy program that have in some ways exceeded expectations, but are still in the testing and preoperational stage. We continue to have high hopes for this innovative, if labor intensive, part of the program.

### *Dissolved Oxygen*

Time series dissolved oxygen measurements have been uncommon in oceanography because of inherent stability problems with sensor calibration. The process of measurement itself changes the calibration so that the sensor drifts significantly over time. This problem has resisted concerted efforts to solve it. Recent technological advances raised the prospects of long-term moored DO measurements. The GoMOOS

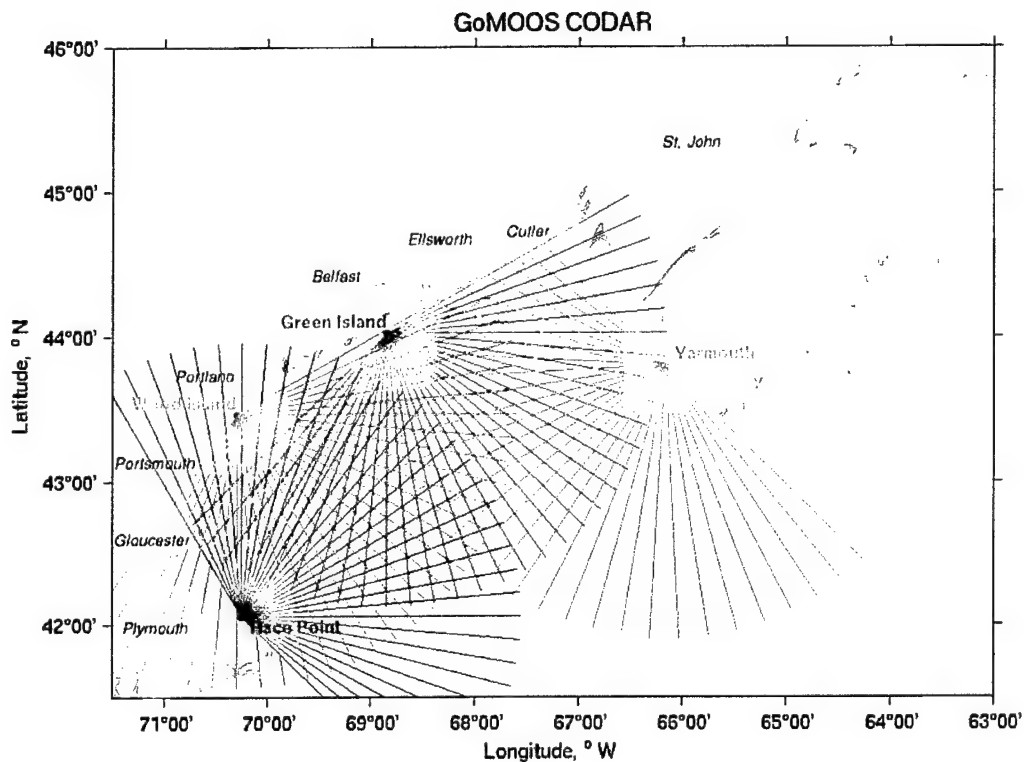
buoy program has been testing the first of the new generation of sensors produced by Sea Bird Instruments Inc. The initial results have exceeded expectations with the sensors exhibiting an order of magnitude more stability than its predecessors. It should be noted that Aanderra Instruments has also introduced a new sensor, the Optode, that utilizes optical technology to measure DO. We are presently testing this sensor as well, but do not yet now the results.

Below is a plot of dissolved oxygen -- March 2002 through November 2002 at 20 m for buoy C in Casco Bay. Similar results are available at 50 m depth for Buoy A in Massachusetts Bay. The results are both surprising and exciting from the scientific and technical points of view. First note the extreme variation of DO over the season in a relatively open region where residence times are short. The recorded values range from nearly 120% saturation to less than 60% saturation. This type of variability has important implications for the clean water standard of Maine Bays and estuaries where 85% is the standard for most of the GOM coastal regions. Detailed records are beginning to provide insight into seasonal and shorter time scale variations and into the physics of the fall recharge associated with cooling event and wind events.



From the technical point of view the data record are equally exciting. Buoy C and the oxygen sensor were replaced on October 3, 2002. The plot shown above is without any post deployment recalibration and shows that the two records join smoothly. The new sensor and that which had been deployed for more than 7 months before show no significant difference in DO levels. These early results show that we have reached the era of practical long-term DO monitoring in the coastal ocean.

### *Long-range CODAR Program*



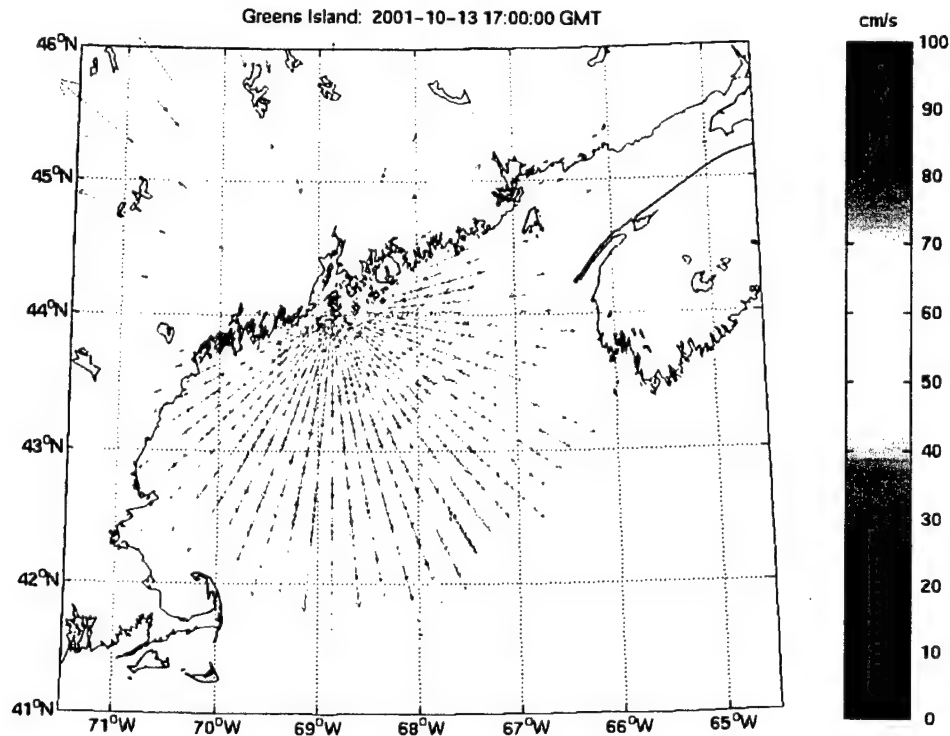
HF radars have been used for several decades to measure surface currents. Until recently their range was limited to roughly 50 km and there was very little to comparison with in situ current measurements to show that the technique actually worked. However, recent developments and testing made CODAR a natural research and development project for GoMOOS.

The new long range CODAR (radio frequency ~5 kHz, range ~200 km) was being tested during the conceptual-development period of the GoMOOS proposal. The range of CODAR's new long-range system was expected to be sufficiently long that four strategically placed units could cover the whole GOM (see diagram above). At the same time new test results from Professor Glenn at Rutgers University had shown an excellent correlation between high resolution CODAR and tidal currents measured by Acoustic Doppler Profilers.

The first GoMOOS CODAR station was installed in the early fall of 2001 on Greens Island near the mouth of Penobscot Bay along the central GOM coast. Early tests of the performance of this unit have been excellent. The range and azimuthal coverage from

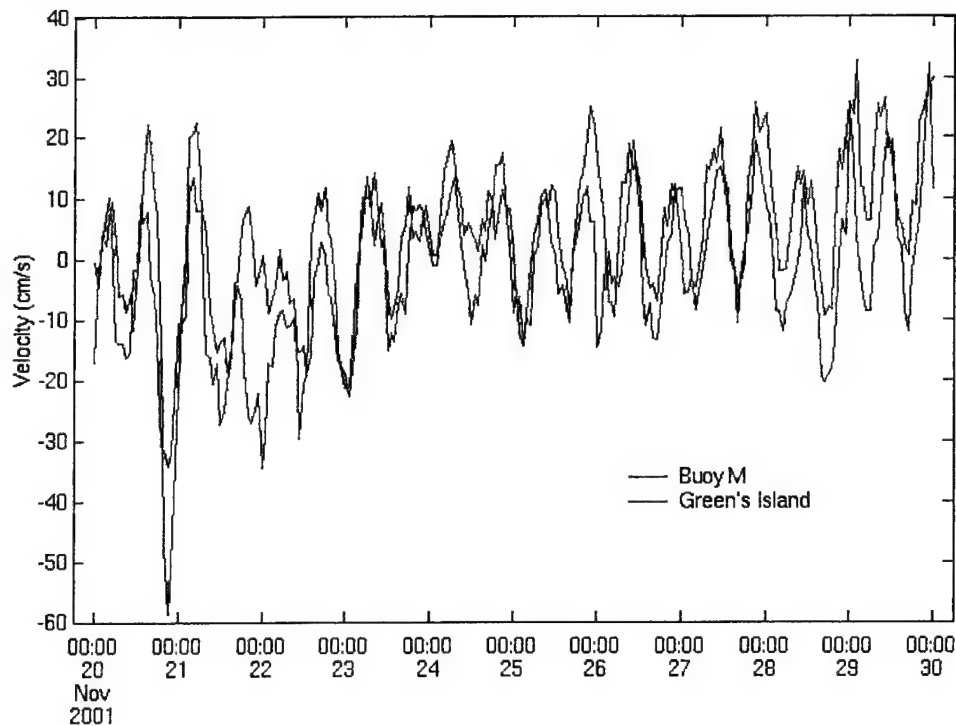


this location at times exceeded 200 km and 180°. However, it was discovered that nighttime ranges were curtailed by ionospheric radio interference. By trying different frequencies, this effect was reduced although not eliminated.



The picture above shows a good example of the daytime range and azimuthal coverage of the long range CODAR at the Greens Island site. This plot clearly demonstrates the great potential of this technology for coverage of the surface currents in the GOM under favorable conditions.

A single CODAR installation is capable of resolving only the radial component of the surface flow field (as shown above). Thus, data from two CODAR installations, whose radials intersect, are required to resolve the horizontal flow field. Since our CODAR system remains largely uninstalled at present we do not have two-dimensional records at any GoMOOS buoy location for direct current comparisons. However, preliminary comparisons between the CODAR radials of the Greens Island site and calculated radials for Buoy M in the Jordan Basin show excellent correlation and overall good agreement.



The plot above shows the comparison between CODAR radials and the surface currents measured by the Aanderraa RCM-9 acoustic Doppler Current meter at 2 m at buoy M (see map on page 3). The CODAR measures currents averaged over an area of approximately 50 km<sup>2</sup> at site M, whereas the current meter is a point measurement. Given these sampling differences the comparison is very good and shows the great promise of the new long-range CODAR system.

A second CODAR unit was deployed in late fall of 2001 at Provincetown, Cape Cod Massachusetts (see site map on page 3). This site is not as favorable in terms of either range or azimuthal coverage, and the day/night range variations are more pronounced.

Overall, the GoMOOS CODAR program shows great promise, but has been problematic during the implementation period. The US Coast Guard has shut down the CODAR unit at Greens Island, and has so far refused to discuss an application for the third planned site at Wood Island near Biddeford Maine. The initial reasons for Coast Guard resistance to CODAR installations stemmed from worries about interference with USCG radio communications with automated lighthouses at both the Greens Island and Wood Island sites. The USCG has experienced ongoing communications problems at Greens Island but they have been shown not to be related to the GoMOOS CODAR installation, and have continued after the USGC shut down the CODAR unit. We continue to try to work

with the USCG authorities to obtain permission, but have not made significant progress in this regard for the last 6 months.

Permission to install CODAR at a fourth site at St. Mary's Point in Nova Scotia is progressing slowly. We hope to have all four sites operational in the summer of 2003.

*Buoy and CODAR Program Progress Summary*

GoMOOS demonstrated early success and continues to improve as GoMOOS transitions to operational status. Buoys have proven rugged enough to withstand the severe winter environment in the GOM, and their real-time data delivery has proven reliable. Early mechanical problems with the mounting of the optical packages have been overcome, as have excessive power drains that caused the premature battery failure of several instruments. Overall the GoMOOS buoy system has been a reliable and versatile performer. We expect continued improvements when funding becomes available to include the deployment of multiple sensors for crucial data products (eg., meteorological sensors).

The new long-range CODAR system shows great promise for remotely sensing surface currents over the bulk of the GOM. Day/night range variability seems to be an inherent feature of the frequency used so that coverage will not be continuous at all locations. The biggest challenge for the CODAR program continues to be getting permission to install sites along the coast, and the USCG has been a particularly difficult partner to deal with.

## Offshore Buoys

*James D. Irish, Woods Hole Oceanographic Institution*

### *Jordan Basin Buoy*

The initial WHOI proposal was to prepare and deploy a GLOBEC-style buoy and mooring systems in Jordan Basin using existing buoys with solar power, data systems, elastic tethers, sensors and GOES (Geostationary Operational Environmental Satellite) telemetry that has worked well in the Gulf of Maine. During proposal revisions, the request for the addition of a surface current meter could be handled by the existing data system (as an ADCP was successfully integrated previously). In the final revision, the task of measuring waves was added with some hardware costs but no personnel time. Also, some bio-optical sensors on some moorings was discussed, but not any interfacing requirements. These last additions exceeded the capability of the old buoy systems, but it was decided that a separate microcontroller might solve the problem. After receiving the initial funding, it became apparent that the bio-optical sensors were required on the Jordan Basin buoy, and no existing data system could handle the radiation, fluorometers and hydrophones envisioned by Bigelow investigators. Therefore, to become more compatible with the U. Maine GoMOOS moorings, and meet some of the bio-optical program's data requirements, WHOI switched to a Campbell Scientific CR23X data system (with additional hardware funding through U. Maine).

This new Campbell system had the capability of: (1) sampling acceleration (analog voltage) at 2 Hz for 2048 points (17 minutes), to provide measurements of waves comparable with NDBC techniques, (2) switching power to all sensors at appropriate sampling time to conserve power usage, (3) multiplexing the SeaBird temperature and conductivity sensors, and sampling sensor frequency every minute, (4) receiving serial data input from two bio-optical packages and two current meters, (5) processing all these data (i.e. calculate means, vector components, FFTs, and statistics), and (6) transmitting (with the new Seimac high baud rate GOES transmitter) the data to shore hourly. The initial cost savings of using the existing WHOI GLOBEC moorings' data systems was lost, and saving further reduced by the additional cost of the mooring cable with conductors.

The program was delayed due to the late distribution of the full program funding. By that time, a GLOBEC buoy with Synergetics data system was readied to deploy with surface currents, temperature and salinity and winds based on the initial proposal. Therefore, integrating the new Campbell data system and learning the software so that we could program a sampling program further delayed the deployment. The Campbell data system lacked the GOES telemetry capability (or any global system) required for the basin buoy. The new Seimac GOES unit (for land use with directional antenna) was the only option available without significant development efforts, so it was used with mixed success (see Seimac GOES transmitter discussion below). With the data system, and late delivery of the mooring cable, the first Jordan Basin mooring was finally deployed in July 2001, about 6 months after full funding. Although later than requested, taking 6 months to start a program, change direction, acquire, checkout and program a new data system was quite an accomplishment.

While the buoy was being assembled, the data system setup, programmed and tested and sensors interfaced, the data management portion of the program was begun. Cron scheduled jobs were written to collect the GOES data hourly from NESDIS. The data were normalized to engineering units with the latest calibrations constants, a first order filter applied to replace unrealistic data with flagged values, and the data archived. The data was then sent to the WHOI FTP site where it could be accessed easily by others in the program. As part of this processing, the bio-optical data (over half the data) were split out of the data stream and sent to Bigelow Laboratories for normalization, analysis and serving to the GoMOOS web site.

To track the buoy should it break loose, and an ARGOS transmitter was added. The ARGOS ADS (automated data service) was set up so that ARGOS would send the positions data daily to the LINUX PC handling the data. This PC would then check to see that the buoy was still in position, and if not send alerts to several people who could then go about tracking and retrieving the buoy.

After deploying the Jordan Basin buoy, I reviewed the program, the WHOI contribution and where I thought GoMOOS should be heading. It became clear that it makes more sense to have one mooring group, and that U. Maine should assume the lead of the mooring program, with WHOI continuing to supply hardware, elastic tethers, subsurface flotation and acoustic release with anchors in year three to assist this process. A program of this size cannot afford to have two different groups doing the same task, as duplication of effort wastes time and money. Then, by not having to prepare and deploy a GoMOOS mooring, I would have time to properly address and solve the wave measuring issue and work with U. Maine on the Basin telemetry issue.

Some critical issues not fully addressed at proposal time were:

1. Bio-optical program plans and the requirements put on the buoys data system for power, mounting and telemetry.
2. Waves observations were an important part, but no discussions and studies of optimal approach and appropriate budget and level of effort were made,
3. Satellite telemetry issue for basin buoys

#### *Deployments:*

*First deployment: July 2001 into Jan 2002.*

Instruments included air temperature, wind speed and direction, Photosynthetically Active Radiation (PAR), temperature and salinity at 1, 5, 30, 80, 130, 180, 230 and 283 m, surface currents, ADCP velocities in the upper 100 m, chlorophyll-a and fluorometer observations at 5 and 30 m, and downwelling irradiation observations on the buoy, at 3 and 30 meters. The data system worked well the whole time, but the GOES transmitter failed in August due to flooding of the Seimac GPS antenna required for the GOES transmitter's timing. The ADCP profiler and 283-m Microcat were self-recording and recorded good data. Although the telemetry failed, the data system continued to work and saved the data from the complete deployment.

*Second deployment: June 2002 through present.*

The sensors were at the same depths and in the same configuration as in the first deployment. The GOES unit was replaced with a new one, the antenna replaced with a weatherproof unit and the system tested for about four months in the laboratory and in the buoy prior to deployment. After 64 days the data telemetry failed in early August. ARGOS transmissions indicate the buoy still in position with good battery voltages and hopefully recording data until replacement can be deployed in Oct 2002. Evaluation of the telemetered data showed no indication of why the system failed again. The next deployment will require a different telemetry scheme, and an evaluation of options should be made as soon as the failure of the present mooring is evaluated.

*Instrumentation/Component Tests/Evaluations*

*Compass for wind direction.*

The KVH AC75 compass used in GLOBEC was no longer made. A comparison was made between the R.M. Young Model 32500 fluxgate compass (readily available) and the KVH AC75 to evaluate its performance as a replacement on GoMOOS moorings. The R.M. Young unit is fully compatible with their Model 5106 Anemometer and also interfaces with other met sensors with analog sensors to produce serial output for logging as well as analog. Sampling was 4 minutes before and after the hour with 2 Hz sampling of wind speed and 1-minute samples of wind direction averaged similarly from both compasses. (The KVH compass outputs the sine and cosine of the direction, which is optimized for calculating velocity vectors, but not as good for simple direction). The compasses were aligned by eye, and the mean difference in the 170-day deployment 1 was 1.6° with a standard deviation of 8.8°. The telemetered data from deployment 2 had a 2.5° mean difference with a 7.2° standard deviation. Several outlying points were as large as 40° and most less than 20°. The largest differences generally occurred at the zero "wraparound" of one compass or the other. Results indicated that the two compasses are comparable and the readily available R.M. Young compass should work as well as the KVH.

*Seimac GOES transmitter with the Campbell data system.*

Being forced into the Campbell data system to be compatible with GoMOOS and handle the additional sensors, there was no available Campbell satellite transmitter that would work from offshore oceanographic buoys. We tried out the new Seimac high-speed unit designed for stationary applications with fixed, directional high-gain antennas. With an omnidirectional antenna on a buoy, the signal received at the satellite was 10 db down from standard levels, and marginal. As there was no readily available option, a unit was purchased and tested on land. It appeared to work (with only occasional dropped or short transmissions) and was integrated into the buoy. During deployment one it worked for just over a month and quit, transmitting occasionally thereafter. The failure was traced to the GPS antenna whose cable had leaked water down to the transmitter.

For the second deployment a second Seimac unit was obtained and interfaced with a Garman GPS antenna and cable that were tested in the laboratory for several months

without problems. The high-speed option was tested and worked (but not as well), but as the time slot allocated was so short, more data could be relayed at the old 100-baud rate. The system was deployed and quit after 64 days of adequate working. Clearly, the Campbell/Seimac solution was not satisfactory and other options should be investigated.

#### *Iridium Telemetry.*

An Iridium phone was purchased by GoMOOS and tested with an ongoing NOPP telemetry program in Massachusetts Bay. The phone was used as the receiving end and to test with another phone data system that did not have a keypad and LCD display. After many growing pains, the system is deployed and working well, except the cost of hourly telemetry is higher than desired. Another alternative used by the Texas Automated Buoy System in the Gulf of Mexico is Global Star (another Low Earth Orbiting satellite system), which has a similar price, was easily to interface to a Tattletale data system, and works reliably. Also, GoMOOS may want to consider every other hour transmissions scheme on remote buoys to reduce costs and optimize the 1 minute Iridium or Global Star transmission block usage.

#### *Aanderaa and MAVS current meters.*

Initially, GoMOOS selected the MAVS3 current meters for surface current observations on the buoys, so this program purchased one for the first deployment. Meanwhile, Nelson Hogg (WHOI) conducted a comparison at the Bermuda mooring with an Aanderaa RCM-11, MAVS2, FSI and VACM current meters. Regression analysis showed that the Aanderaa agreed better with the VACMs than the MAVS did, and the MAVS appeared to be overspeeding. Therefore, GoMOOS switched to Aanderaa RCM-9 current meters. Further analysis of this data set, particularly the MAVS and VACM data, showed that the VACM often stalled in the slow currents and the MAVS travel time measurement did not. To account for the good agreement with the VACM, the RCM-11 must also have "stalled" - probably because of the lack of acoustic scatterers in the clear water off Bermuda. This indicated that very low velocity regimes are not good environments to conduct current meter tests, but little else. Tow tank tests of the new GoMOOS MAVS and one of the VACMs from the test confirmed that they both were working properly and giving expected results. Therefore, the Bermuda test was inconclusive for evaluating current meter performance for the Gulf of Maine applications.

To further evaluate the MAVS and Aanderaa current meters, a comparison was made on the Jordan Basin mooring between a MAVS3 at 2.74-m depth and an Aanderaa RCM-9 at 1.73-m depth. During the first deployment, the instruments were not set to sample at the same time, so comparison would be meaningless. On the second deployment, both current meters were set to burst sample at 1 Hz for 1-minute averages at 3 minutes after each hour (sampling dictated by the restricted Aanderaa sampling options). The mooring is not recovered so the full data set not available, but the telemetered data indicate a reasonable comparison. The Aanderaa velocities are generally higher than the MAVS (mean difference of 3.71 cm/sec), but the Aanderaa was at 1.7-m depth and the MAVS at 2.7 m. The ADCP in the first deployment showed slower velocities at greater depths, and it is reasonable to assume a decreasing wind driven velocity profile with depth so that this difference is quite reasonable. Fitting a least squares fit to the data shows a zero intercept



of 2.95 cm/sec and a slope of 1.036 (Aanderaa/Mavs). Hence the criticism of the MAVS overspeeding does not show up here, and a 3% difference could be made up by the sound velocity estimate which enters into each current meter estimate. A more disconcerting result is that the standard deviation of the difference is 5.17 cm/sec with a max difference of 31.1 cm/sec and a minimum of -14.6 cm/sec. The large scatter is probably due to the large scatter of the measurements made in the upper three meters of the water column and probably indicative of the problem of measuring near surface currents rather than inherent differences in the current meters. Also, there is a correlation between large velocity differences, and wind speed, as would be expected if the difference were due to wind driven flow that varied with depth. However, the semidiurnal tides are obvious in the velocities, and being more barotropic would dominate when wind velocities are low. A paper on these results is being prepared for presentation at the Current Meter Technology Conference in San Diego next spring.

*Crossbow and Summit Instruments accelerometers.*

Based on previous WHOI work (Mark Grosenbaugh and Jason Gobat in Primer and at the WHOI Buoy Farm) a Summit Instruments accelerometer was selected for a wave-measuring buoy deployed off NH as part of an offshore aquaculture demonstration program by Jim Irish (WHOI) and Dave Fredriksson (UNH). This system worked well and the same accelerometer was selected for use in GoMOOS as it appeared to work and fit the prescribed budget. As a further test of low-cost accelerometers options, a CrossBow unit was acquired and simultaneously deployed and sampled on the Jordan Basin mooring. Initial indications are that either accelerometer would work adequately and provide similar results.

There are several problems in using acceleration to measure waves. The first assumes that the buoy is an exact wave following platform. This is not so, but in larger waves it is a close approximation. Further study of this will be done next year. Second, is the fact that the buoy tilts with the waves, and a strapdown accelerometer (fixed to the buoy hull) will see a changing acceleration due to gravity as the buoy tilts that is not due to the vertical motion of the waves. This results in "spillage" of energy from the wave bands to background levels both above and below the wave band. The third problem is that we integrate the acceleration twice to get vertical displacement. This selectively amplifies the low frequency accelerometer noise, including the wave spillage noise, so that at lowest frequencies it is often larger than the wave peak. One can do a first order correction for the spillage by subtracting a high frequency signal out of the wave band from the acceleration, and noting that there is a notch between the wave band and the noise at low frequency. A solution is to apply a high pass filter, or drop the lowest frequency estimates. A Butterworth filter with a 20 second cutoff worked well on the NH wave data, but doesn't work as well on the GoMOOS moorings. This may be because the NH wave buoy utilized an elastic tether mooring that kept the buoy from tilting as much. The first Jordan Basin mooring also appeared to have a similar behavior, but the present deployment appears to have the largest energy in the first estimate that often dominates the signal and variance estimate in a manner that doesn't make sense. The simple solution is to drop the lowest spectral estimate (16 second period), but in the U. Maine moorings with 1024-point samples, the next point is at 10 seconds and limits the

amount spectral resolution and peak frequency selected for the significant wave period. These two problems are under continued study to improve the significant wave height and period by selecting the proper noise reduction and cutoff, and validating these observations and techniques with independent wave estimates as will be done in the coming year (see below).

### *Future Directions*

During year three, work will continue in several areas.

- Documenting and assisting with methodology, sampling and QC issues with the moored component of the program.
- Wave observations. The wave measuring portion of the program was a add on with inadequate personnel time allocated to address it, and too small a budget to duplicate NDBC's approach. Therefore, a lower cost approach was taken, but not well understood and optimized for the U. Maine chain catenary moorings. Work is now underway to optimize the code to reduce integration, accelerometer, and buoy tilting effects from the wave estimate. Computations done on time series from a WHOI/UNH mooring off NH were used to develop code that is now being tested on GoMOOS moorings.
- A second area that will be studied is the mooring response to waves to further correct the wave estimates. This will be done by mooring an RD Instruments waves measuring ADCP nearly a GoMOOS mooring and comparing the results to estimate mooring response. The results will be documented and integrated into the GoMOOS program documentation and processing algorithms.
- Providing general feedback and assistance with GoMOOS on "going operational"

## **Real-time Optical Data**

*Collin Roesler, Bigelow Laboratory for Ocean Sciences*

### *Contract Description*

The contract to the Bigelow Laboratory for Ocean Sciences was for the design and development the optical sensing program for implementation of the initial phase of the Gulf of Maine Ocean Observing System (GoMOOS). Dr. Collin Roesler provided oversight of the optical program for GoMOOS. The work tasks included developing instrument packages for deployment on the moored buoy array, in concert with the guidelines provided by University of Maine (Pettigrew) and Woods Hole Oceanographic Institute (Irish), and data processing capacity to provide real-time optical data. The contract was for the design/deployment of: (1) two shelf buoys, heavily instrumented with surface multi-channel radiance and irradiance sensors, absorption meters and backscattering sensors, and a series of paired chlorophyll fluorometers and irradiance sensors located within the euphotic zone; (2) two shelf buoys and a basin buoy instrumented with the series of paired fluorometers/irradiance sensors. The contract for data handling/delivery was (1) the development of computer software to handle routine processing of optical data; (2) to ensure the continuous and routine delivery in near real time to the Gulf of Maine Information Management System (GoMIMS); and (3) work with other principal investigators on the development of integrated data products from the optical data based upon the demands of the user group.

### *Accomplishments and Status*

All the activities presented in this report have been performed by Collin Roesler (project PI) and Andrew Barnard (project Post Doctoral Researcher).

### *Instruments*

A suite of instrumentation for the detection of bio-optical properties (Table 1) was purchased. These instruments, as proposed, provide estimates of spectral absorption, attenuation, backscattering functions, downward irradiance and upward radiance, and chlorophyll fluorescence. Because of communication limitations in the Campbell data logger, we worked with WETLabs, Inc., to design, construct and configure a data handler (DH4) that would provide instrument control, power control, rudimentary data processing, raw data logging, and provide a single stream of data to the Campbell data logger on each mooring. These DH4s communicate directly to the Campbell near surface instrument packages and via an inductive modem for the deep-water packages. While these were not part of the initial proposal, they were necessary for integration into the existing University of Maine buoy design. These instruments were also designed to activate a failsafe mode in the case that the Campbell communications failed. In the event that no hourly sampling command was received from the Campbell, the DH4 initiates it own sampling and data storage so that upon retrieval, the entire data set of high resolution time series are retrieved. This mode has been implemented and resulted in months of rescued data.

### *Biofouling*

Chlorophyll fluorometers and backscattering sensors were purchased with integrated copper shutter systems. These anti-biofouling agents were demonstrated to work remarkably well, with minimal fouling impacts after 6 months of deployment. Irradiance and radiance sensors were initially deployed with minimal anti-biofouling precautions (copper foil around sensing heads). Some fouling was observed upon recovery. Working with Satlantic, Inc., a copper shutter system was designed and manufactured to mitigate fouling on the sensor heads. These shutters rotate out of the detection plane while instruments collect data, software had to be modified to ignore those observations taken while impacted by shutter. All packages are now equipped with shutters. The ac9 was equipped with 25 cm of copper tubing on both the intake and outflow ports of both the a and c sampling tubes. This tubing allows copper to dissolve and fill the sample volume in between samples. The instrument is programmed to flush this water out before the start of sampling. After 6 months no evidence of biofouling was observed in the data or on the optical sensing surfaces. These anti-biofouling steps enabled us to deploy the optical packages for the full 6-month deployment without having to service them every three months as had been planned in the original proposal. The extreme success in our anti-biofouling program necessitated that we purchase double battery power for each package to power instruments for 6-month deployments.

### *Calibration/Characterization*

All instruments undergo a careful and complete calibration and/or characterization when they are received from the company. Calibration is performed with pure water and in some cases known standards. These same calibrations are performed upon mooring recovery before any organic coatings can dry so as to quantify any drift due to biofouling. Instruments are then thoroughly clean and recalibrated to quantify instrument drift during deployment. These two quantities can then be used to back calculate data and data products if necessary.

Data analysis from deployments pointed to a temperature dependence in the signals from the chlorophyll fluorometers and the light sensors. We developed a full temperature characterization scheme to quantify this dependence. It is now incorporated into the data processing software.

### *Package Descriptions*

Instrument packages for each mooring are described in Table 1. Briefly, we designed three package types: the surface irradiance package, the underwater phytoplankton biomass/production package, and the underwater ocean color package. All optical moorings have the surface irradiance package, which consists of a 4- or 7-wavelength downward irradiance sensor and a data handler (DH4, which is configured within the well of the buoy). All optical moorings have the underwater phytoplankton biomass/production packages in the lower portion of the euphotic zone (approximately 18 - 30 m, depending upon location) and B, L, and M have had these packages deployed subsurface as well (~3m depth). These packages consist of paired chlorophyll fluorometers and 4 channel downward irradiance sensors. Moorings E and I have the ocean color packages deployed at the subsurface depth (~3m). The ocean color packages have a 7-channel upward radiance sensor, a nine-wavelength absorption-attenuation

meter, and a three wavelength, three angle backscattering sensor in addition to the chlorophyll fluorometer and irradiance sensor. At these two sites the surface irradiance sensor is the 7-channel variety.

#### *Deployment/Operational History*

The deployment history of the instrument packages is shown in Table 2. While there are some gaps in the data, none of these have been due to instrument failure. The largest source of failure has been in the Campbell-optics communication protocols and in cable damage. Even in the case in which moorings were lost (either cables cut or buoys lost), once recovered, the data loggers demonstrate that hourly sampling was maintained for months afterwards (although data collected at the bottom of the GoM is not relevant to the program).

Because of limitations in funding, we did not have sufficient inventory for redundancy. This necessitated instrument turnaround during deployments. The process involves retrieving instruments immediately after recovery on deck, calibrating each sensor, cleaning thoroughly, recalibrating, downloading all stored data, changing out batteries, replacing cables, and preparing for redeployment. Depending upon the mooring schedule, these redeployments involved a number of hours on station. We requested redundancy in the last funding cycle to alleviate the bottleneck in redeployment operations and to provide ample time for instrument refurbishment in the laboratory.

#### *Data handling/delivery*

All data from the optical packages are collected and logged on the DH4 cards. This data is retrieved and processed after recovery and these are the data that will be used to update the database and web pages. The real time hourly observations are reduced to means by the DH4 firmware and communicated to the Campbell system either directly or via inductive modem for transmission over the cell phone. Data are extracted from the data stream at University of Maine and delivered hourly via ftp (Python script) to our computer at Bigelow. The data are processed to geophysical units (calibrations applied) and products are computed (using developed algorithms) using Matlab scripts. These scripts include quality control and assurance subroutines on all instrumentation. Both raw and processed data and data products are archived and are written to daily files for each mooring. These files are updated hourly, and are made available to the GoMOOS information system under a public http area.

#### *Data Products*

We originally proposed to produce the following data products: chlorophyll concentration, spectral downwelling irradiance, spectral upwelling radiance, spectral diffuse attenuation, downwelling irradiance of PAR, spectral absorption, scattering, backscattering, and beam attenuation coefficients. In addition to these we are producing: clear sky atmosphere spectral downwelling irradiance, clear sky atmosphere downwelling irradiance of PAR, percent cloud cover, cloud conditions, depth of percent light level, gross integrated primary production, underwater visibility, water color, water turbidity, remote sensing reflectance, community structure, and a blooms index.

### *Difference Between Current and Proposed Program*

#### *Continuous Deployment on Five Moorings*

While we had planned to deploy optical packages on five moorings, and we have had instruments deployed on B, E, I, L, and M, the loss of L for 7 months made us reconsider that location for our small program. In the mean time we had to put funds for (1) the development and purchase of DH4 units for all packages, (2) additional batteries (for 6 month deployments) for all packages, (3) complete cable replacement for each deployment due to excessive wear during deployment, (4) shutters for irradiance sensors. These additional expenditures meant that we only had sufficient funds for 4 complete moorings. We have also found that the lack of redundancy makes for very difficult recovery/redeployment cruises. Thus the few pieces of instrumentation that were in reserve have been put towards the development of redundant instrument packages.

*All other differences are described above as accomplishments as we accomplished more than we had proposed.*

#### *Transition to an Operational Observing System*

We are working towards the goal of making the purchase, calibration, and deployment/recovery of our optical program operational and transferable to any observing system. The steps that we have taken towards this goal are as follows:

*System Design-* All of our instrument packages are stand-alone. The modification of the original proposed packages to the current package includes the DH4 data handler, which allows for independent control on all instrumentation, instrument power, in situ data processing and data transmission via rs232 protocols. These systems can be placed on any mooring and can provide data streams in any required format.

#### *Instrument Design*

All of our instrument packages are off the shelf. There is no additional engineering required for them to be operational.

#### *Instrument Calibration and Characterization*

All instruments come from the factory calibrated. Given 100% redundancy, it would be possible to return instruments to factory for calibration between deployments. However, it is very important for instruments to be post calibrated right out of the water to properly characterize biofouling. Additionally, they need to be cleaned and calibrated again to quantify instrument drift. This needs to be performed during the deployment/recovery cruises by a trained technician with oversight by a trained professional (i.e. PI or equivalent). Factory supplied instruments are not characterized. These characterizations are necessary to discern real signals from artifacts and must be performed by a trained professional. Some of the steps could become routine for a trained technician with oversight by a trained professional.

#### *Data Quality Control and Assurance*

All data are put through qc/qa at the processing level based upon a standardized criteria. However, there are a number of instances in which it is necessary to validate signals



using ancillary data. We are developing schemes for such validation but it is likely that this type of assurance may never be operational.

#### *Data Interpretation*

As with data qc/qa, this will not be an operational mode for observing systems, as it requires a trained professional scientist.

Table 1. Model, description, manufacturer and product derived all or in part by the observation, of bio-optical instruments deployed on the GoMOOS moorings. STD and OC refer to package type, STD is the standard paired chlorophyll fluorometer and light sensors, OC is the ocean color package which has additionally, ac9, vsf, Lu on the subsurface package and a 7 wavelength irradiance sensor instead of the 4 wavelength on the surface package. Surface packages sit on the buoy, subsurface packages at ~3m and deep packages between 18 and 30 m depending upon mooring site.





Model	Description	Manufacturer	Derived Products	Package Depth, Package Type
OC504CSA	4 wavelength irradiance sensor, in air	Satlantic	incident irradiance, %of clear sky radiation, radiance reflect	surface, STD
OC504CSW	4 wavelength irradiance sensor, in water	Satlantic	PAR, spectral diffuse attenuation coefficient, light penetration depth, primary production	subsurface, all deep, all
OC507CSA	7 wavelength irradiance sensor, in air	Satlantic	incident irradiance, %of clear sky radiation, radiance reflectance	surface, OC
OC507R10W	7 wavelength radiance sensor, in water	Satlantic	spectral water leaving radiance, radiance reflectance, satellite-derived products	subsurface, OC
ac9	9 wavelength absorption and attenuation meter	WETLabs	spectral absorption and attenuation coefficients, turbidity (beam attenuation), constituent composition (phytoplankton biomass, non-algal particles, dissolved matter) and concentration, particle size distribution	subsurface, OC
VSF3	3 angle, 3 wavelength backscattering meter	WETLabs	spectral backscattering coefficients, backward volume scattering function, ocean color validation, bulk particle concentration and composition	subsurface, OC
DFLS	chlorophyll fluorometer	WETLabs	chlorophyll concentration, phytoplankton biomass, phytoplankton production	subsurface, all deep, all
DH4, DH4NC	data handler	WETLabs	controls, powers and integrates instrumentation, logs raw data, computes statistics, transfers means to Campbell data system.	subsurface, all deep, all



DH4NC	no-can data handler	WETLabs	NC refers to No-Can configuration, which sits directly in the buoy well and controls surface irradiance sensors.	surface, all
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Table 2. Deployment history of the bio-optical packages at the five mooring sites. Deployment and recovery dates are indicated. Solid colored indicate dates with real time data transmission, pale colors indicate dates for which transmission did not occur but data was internally logged and retrieved upon recovery. Dots indicate patchy transmission due to communication breakdown (cell phone or cable breaks) or power limitations (e.g. B after 6 month deployment). Hatched indicate logged data retrieved from instrument sitting on bottom (e.g. L, note instrument still working and recording after 11 months at sea!).

		2001					2002									
Mooring	Pkg	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
<b>B</b>	surface															
	3 m															
	18 m															
<b>E</b>	surface			21st												
	3 m				27th											
	18 m															
<b>I</b>	surface															
	3 m															
	18 m															
<b>L</b>	surface															
	3 m	25th						6th								
	18 m															
<b>M</b>	surface							6th							7th	
	3 m															
	30 m															

realtime data   
 archived data only   
 patchy transmission   
 on bottom, but recording 

## Satellite Oceanography

*Andrew Thomas, University of Maine*

### *Overview*

Satellite data, in conjunction with CODAR, are a principal means of obtaining operational synoptic coverage of ocean bio-geophysical parameters of the GOM region, placing *in situ* time series measurements into spatial context. In addition, historical archives and ongoing time series of satellite data provide a temporal context for both real-time satellite data retrievals and any *in situ* data available over short timeframes. The satellite data make possible comparisons of real time observations to a climatological database.

Four satellite data streams were initially targeted for GoMOOS operations, NOAA AVHRR, SeaWiFS, MODIS and QuikSCAT. These data streams provide sea surface temperature (SST), ocean color, and surface wind monitoring capability. The choice of these four data streams was based upon a combination of their suitability for monitoring signals critical to the program, the maturity of the data products that result, and the ease and cost of access and handling. NOAA AVHRR data are available 4-6 times daily at 1.1 km resolution providing SST fields. NASA SeaWiFS data provide multispectral measurements of ocean color, suitable for calculating surface chlorophyll concentration and extinction coefficients. These data are available on a daily basis at 1 km resolution, delivered 2 weeks after acquisition free of charge to NASA-registered investigators. Real-time access requires a license, purchased from Orbimage. NASA MODIS data was anticipated to become available during the first 2 years of GoMOOS operations, providing daily 1 km resolution co-registered ocean color and SST data. Surface wind measurements are available from the NASA QuikSCAT mission. These measurements provide twice daily coverage at 0.25 degree spatial resolution in near real-time for quick-look data and on a time frame approximating 2-4 days after overpass for calibrated data.

### *Accomplishments*

Satellite data received and processed at the University of Maine's Satellite Oceanography Data Laboratory (SODL) was one of the first geophysical products delivered to, and made available by, GoMOOS. The SODL maintains a research web site at WAVY.UMEOCE.MAINE.EDU.

In the first year, Dr. Peter Brickley was hired to assist with GoMOOS data processing. Data processing, archiving and product development tasks within the Satellite Oceanography Data Laboratory at U.Maine are divided between Dr. Brickley and Ryan Weatherbee, both of whom are partially funded by GoMOOS. A team of graduate students assists with day-to-day operations as required. The principal areas of effort in the first two years of GoMOOS were spent in defining and creating operational satellite data derived products, delivering these in a web-based format and identifying and defining database structure issues. All activities and personnel are overseen by Andrew Thomas.

*Wind Vectors ( NASA's QuikSCAT Scatterometer)*

Research quality wind retrievals (Level 3 binned data) for global fields are made available approximately 2-4 days after-the-fact via an ftp site at NASA's Jet Propulsion Laboratory (JPL). We established a direct relationship with the JPL laboratory and have developed automated scripts that retrieve these data into the SODL computer network as they are made available. Automated C-Shell scripts subset and re-map the fields to the Gulf of Maine region. Two parallel information/data products were developed: a) an annotated color coded JPEG for posting to the GoMOOS web site and archiving and b) a Hierarchical Data Format (HDF) data product for archiving. The later is available to interested users and to the database, when it becomes operational.

In 2001, non-research quality, quick-look versions of the wind fields were made available to the community by JPL in near real-time. After interaction with JPL, we developed scripts that automatically retrieve these data, subset and re-map them to the Gulf of Maine study area and now routinely make them available to GoMOOS. The near real time data are archived in-house and delivered to the database. The JPEG images are not archived, but were designed as a quick-look for interested users. These data supplement by the research quality (L3) data stream as they become available days later.

A summary of specific tasks and protocols developed for GoMOOS for the QuikSCAT data stream are given below:

- L3 binned data
- Acquisition of data from JPL PODAAC
- FTP data via C-shell scripts coordinated by cron jobs (data are HDF format)
- Processing and subsetting
- Develop and modify IDL scripts to ingest, subset, QC, and export data in GOMOOS compliant data format (HDF format). Execution is coordinated by cron jobs and C-shell scripts
- Export to GOMOOS data base
- Develop scripts in JAVA to import metadata and data to MySQL database (micmac.umeoce.maine.edu) Execution is coordinated by cron and c-shell script. Imagery was exported to original GOMOOS web page and is exported to SODL web page
- Near Real-Time quick-look data
- Acquisition of data from JPL PODAAC
- FTP from the near Real-Time Server (in VAP RMGDR format). Timing of data acquisition is optimized based on probability of data availability (we conducted tests with technical staff at JPL). FTP data via C-shell scripts executed by time-coordinated cron jobs (data are HDF format)
- Processing and subsetting Develop and modify IDL scripts to ingest, subset, QC, and export data in GOMOOS compliant data format (HDF format). Execution is coordinated by cron jobs and C-shell scripts.
- Export to GOMOOS data base
- Develop scripts in JAVA to import metadata and data to MySQL database (micmac.umeoce.maine.edu) Execution is coordinated by cron and C-shell script

Export of imagery to the original GOMOOS web site. Created a "most-recent" image file for original GOMOOS website.

#### *Surface Chlorophyll (SeaWiFS)*

Scripts were developed that automatically download via ftp L1A SeaWiFS data covering the U.S. eastern seaboard from NASA Goddard Space Flight Center as they are made available in the NASA-defined research mode, which is approximately 2-3 weeks after-the-fact. Daily overpass data are subset to the Gulf of Maine region, processed to chlorophyll values using current NASA global coefficients and remapped to a standard projection matching that of the AVHRR SST data. Scripts were created that composite multiple daily scenes together into both 8-day and monthly composite products, thereby maximizing the ability of view features through clouds. Three products are created, 2 of which are posted onto the SODL web site: daily scenes (HDF files only, archived only), 8-day composites (jpeg available on-line at SODL web site, HDF file archived) and monthly composites (jpeg available on-line at SODL web site, HDF file archived). All products on the SODL website are posted behind statements warning of the proprietary nature of the data and stating that they are for "research use" only. All products are made available to GoMOOS.

In 2001, an alternate ocean color-processing algorithm developed in Belgium (MUMM) was acquired, installed and integrated into the processing scheme. The Belgians reported obtaining improved chlorophyll retrievals in coastal waters, the English Channel and North Sea. Our efforts were carried out in parallel with similar efforts by ocean color researchers working in Chesapeake Bay. A series of tests were carried out using our own Gulf of Maine in situ surface chlorophyll concentration database (acquired under separate funding) as a comparison. Although chlorophyll fields output by the MUMM code differed from those produced by NASA code, we could not see any significant improvement in overall accuracy. Similar results were reported for Chesapeake Bay. We continue to use NASA algorithms.

A BETA version of MODIS chlorophyll products was made available by the NASA MODIS Team in 2001. These data were classified by NASA as "still containing significant errors, unsuitable for quantitative science". We continued to develop code that would handle the data stream, process and navigate the data fields and make products covering the Gulf of Maine region available to GoMOOS. We adapted NASA IDL scripts to remap the MODIS L2 (1 km) chl product to the GoMOOS region and a mercator projection. By the end of the funded period, a research quality data stream had not been made available by NASA and all ocean color products prepared for GoMOOS used the operational and tested SeaWiFS data stream.

A summary of specific tasks and protocols developed for GoMOOS for the SeaWiFS data stream are given below:

- Update processing coefficients and navigation parameters in SEADAS to conform to new NASA Reprocessing #3

- Complete reprocessing of entire SeaWiFS [chl] database for 1997-2000 (summer) into RP#3 to replace RP #2 data
- Customize data flagging thresholds in SEADAS processing to maximize data quality over the Gulf of Maine.
- Updated SeaDAS/IDL scripts to minimize user interaction – a single command script now controls the SeaDAS processing (1 month at a time), manages ancillary files, moves processed files to the SeaWiFS archive directories, creates JPEG images of GOM and subregion study areas, and updates the website – eliminates all user interaction except initiation
- Develop script to post “most recent” 8-day composite on original GoMOOS web site
- Continual modification of image annotation to make it user friendly
- Implement ftp download of LAC data from the DAAC automatically on a daily basis (C-shell script run by a cron job that reads the subscription e-mail, parses out the relevant ftp directory information and ftp’s the DAAC to download the data)

#### *Sea Surface Temperatures (NOAA's AVHRR)*

These data are downloaded in real-time from the NOAA polar orbiting satellites by the SODL Seaspace Terascan © ground station on each overpass. Scripts have been written that automatically archive the raw swath data and pass Gulf of Maine sub scenes into a processing stream. This stream requires daily handling (except weekends) by trained personnel from the SODL to accurately navigate each scene, correcting for slight drift in computer clocks. After this, scripts were developed to process each orbit swath into two remapped, subset, cloud screened, sea surface temperature data products with 1.1km spatial resolution and 0.1°C thermal resolution, a) an annotated colorized jpeg which is posted to the SODL web page and archived and b) a digital data file for archiving. Annotation is added to these products including land masking, a vector coastline map, date, satellite number, and temperature scales in both F and C. Approximately 4-6 scenes are available each day, usually within 24 hours of overpass.

In early 2002, a technician from Seaspace Corp. visited the SODL to check the operational status and wear on all Terascan hardware, to recommend optimal maintenance error diagnosis and system checking procedures and provide detailed instruction in automated scripting and data processing within their software environment.

A summary of specific tasks and protocols developed for GoMOOS for the AVHRR SST data stream are given below:

- Terascan © system maintenance and administration, including:
  - a. Install new software (v 3.1)
  - b. Automate acquisition and export of GOM SST imagery to GOMOOS and SODL web page
  - c. Automate download of revised orbital elements files, automate update of GPS and system clock data
  - d. Test auto-navigation scripts

- e. MCSST algorithm improvements (cloud masking)
- f. Phase out of NOAA-15 , phase in of NOAA-16 and NOAA-17 satellites
- g. Trouble shoot and repair of tracking dish
- h. On-site SeaSpace training in software upgrades and automated processing scripts
- i. Consult with SeaSpace on improvement to software and customizing of certain functions
- j. PERL scripting to automate and parse data products
- k. Automated tape archiving and extraction
- Processing
  - a. Develop and improve IDL scripts to export data in GOMOOS compliant data format (HDF format). Execution is coordinated by cron jobs and C-shell scripts
  - b. Export to GOMOOS data base
  - c. Develop scripts in JAVA to import metadata and data to MySQL database (micmac.umeoce.maine.edu) Execution is coordinated by cron and c-shell script
  - d. Imagery exported to original GOMOOS web page and to SODL web page

#### *Data Management Efforts*

- SODL staff attended weekly or bi-weekly meetings chaired by Kate Beard with U.Maine GOMOOS IT staff from satellite, buoy, modeling, wave modeling, and spatial information groups (2000-2001).
- Designed parallel data management schema for both Oracle v9 and MySQL databases.
- Implemented MySQL data scheme for satellite data, imported available data from 1999 onward.
- Worked with buoy group to develop original GoMOOS web site that displayed all satellite data products
- SODL staff worked with buoy group to implement JAVA scripting to handle HDF formatted files. (This has now been changed and we will secure-copy data directly to the central U.Maine GoMOOS server (micmac.umeoce.maine.edu), where the buoy group will handle data import.).
- Developed Metadata sheets (ISO Standard) for AVHRR MCSST, SeaWiFS [chl] and QuikSCAT Wind data products – these sheets were delivered to and accepted by Kate Beard
- Updated SODL Website to include product descriptions, georeferencing metadata, links to “Mission Status” information, and links to product viewing software for potential use by GoMOOS users
- Purchased, installed and configured a Linux Redhat based RAID system for storage of all GoMOOS related data products (partially funded by GoMOOS)
- Purchased, installed and configured a second Linux Redhat based CPU to provide additional processing capabilities (partially funded by GoMOOS)
- Developed and initiated a SODL network-wide backup/archive system to systematically and automatically backup all SODL disk space

*Current SODL Computational Environment*

- Heterogeneous UNIX – LINUX – PC network
- 2 RAID servers (Linux RH dual-Xeon) and SCSI disk farm (~ 0.6 Tb available on-line storage)
- 4 Sun's, 2 Linux CPU units (NFS networked) for in-house processing and staging to GOMOOS
- Tape archive system (DLT, SDLT, dual DAT)
- HRPT reception system: rooftop 0.46 m tracking dish, GPS, RF and digitizing electronics, dedicated Ultrasparc system w/ customized software for processing, tape archiving, and updating of orbital elements
- 100 Mb/s ethernet



## Circulation Modeling

*Huijie Xue, University of Maine*

The GoMOOS circulation modeling focuses on applying operational numerical models to the Gulf of Maine region, making model results available via the web in real time in nowcast mode, and producing forecasts by coupling the circulation model with available meteorological forecasts. The great strengths of mathematical models from the observatory perspective are interpolation, extrapolation, integration, and prediction. This report summarizes the completed and the ongoing tasks of the modeling group at the University of Maine.

A major task listed in the original proposal is to develop a data assimilation algorithm to incorporate CODAR measured sea surface velocity into the operational daily forecasts. This task has been delayed due to the delays encountered during CODAR installation. We have finished coding the algorithm, but testing of the code is hampered by data quality. We are working closely with the GoMOOS CODAR group to resolve the problem and hope to include assimilation of surface velocity in the next version of the forecast system. On the other hand, since temperature is an important index for fisheries, we decided to focus on the quality of the model predicted temperature. A scheme that assimilated the real-time AVHRR data has been incorporated in the forecast system since June 2001. The scheme generates robust sea surface temperature patterns and the modeled sea surface temperature can be used to fill in the data gaps of the satellite SST. The following section describes the current version of the forecast system. Section 2 and 3 summarize the data assimilation schemes used in the forecast system and the analysis tools developed for forecast error assessment. The last section describes the ongoing tasks for year three.

### *The Gulf of Maine circulation forecast system*

The Gulf of Maine circulation forecasts system is based on the three-dimensional Princeton Ocean Model in a curvilinear grid (Figure 1). It is driven at the surface by heat, moisture, and momentum fluxes from the National Center for Environmental Prediction (NCEP)'s Eta mesoscale atmospheric forecast model. Boundary forcing includes daily river outflows from St. John, Penobscot, Kennebec, Androscoggin, Saco, and Merrimack, tidal

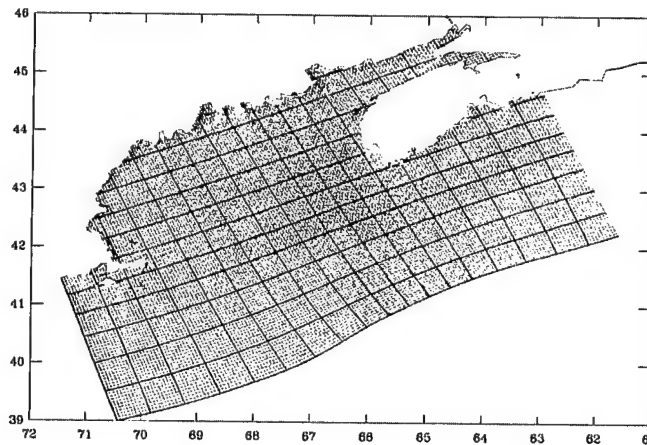


Figure 1. The Gulf of Maine circulation model grid.

( $M_2$ ,  $S_2$ ,  $N_2$ ,  $K_1$ ,  $O_1$ , and  $P_1$ ) and subtidal forcing from the open ocean, which is interpolated from the daily nowcast of the NCEP Coastal Ocean Forecast System (COFS).

The daily procedure, which starts at 6:00 am everyday, includes three consecutive jobs: preprocessing, model integration, and post processing. Preprocessing consists of a series of automated scripts, which download the river discharge, AVHRR, Eta and COFS forecasts, and interpolate them to the Gulf of Maine grid. Handling missing data is a critical step. For short-term disruption of river discharge data, the last valid number is carried forward. Climatological monthly mean is used during extensive ice period during winter. For AVHRR, a composite of the last eight days is formed to minimize the cloud cover and, if there still clouds, an 8-day climatology from the same Julian days is used to fill in the cloudy spots. Missing COFS data is usually substituted using the COFS output of the last available date with tidal correction, which work well for interruptions up to a week. Similarly, the last available Eta forecast is used to substitute for missing Eta data. This, however, can result in considerable errors. We are developing a redundant system with the meteorological and open ocean forcing from FNMOC and NAVO. We have started to archive SWAFS's and COAMPS forecasts over the Gulf of Maine region. The two parallel forecasts will not only minimize the interruption of our daily operation, but also provide quality assessment of ETA/COFS (NOAA) and COAMPS/SWAFS (Navy) forecasts over the region.

Upon the completion of preprocessing, which supplies the necessary boundary condition, the automated daily procedure calls for the model integration session (figure 2). A 24-hour nowcast cycle assimilates the satellite SST (see details below) and prepares the initial condition for the next 48-hour forecast. Post-processing includes data storage, web interface, and error assessment (see details below). Model output of every 3 hours has been archived since 1 January 2001, and daily restart files have been saved incrementally for hindcasts of specific events in the future. Temperature, salinity and velocity at three levels and surface elevation are shown graphically on the web at a 3-hour interval (Figure 3). The GoMOOS circulation forecast system is currently running on both the SGI Origin 3200 and a dual processor PC. The daily procedure takes about 20 minutes on the SGI and about 2 hours on the PC.

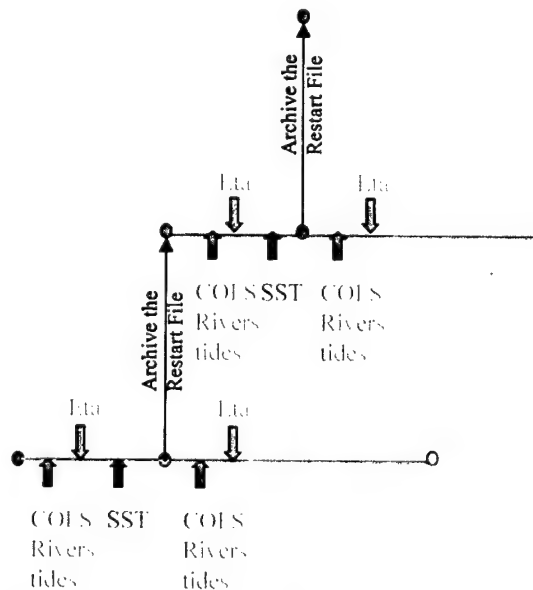


Figure 2. Schematic of daily model integration.

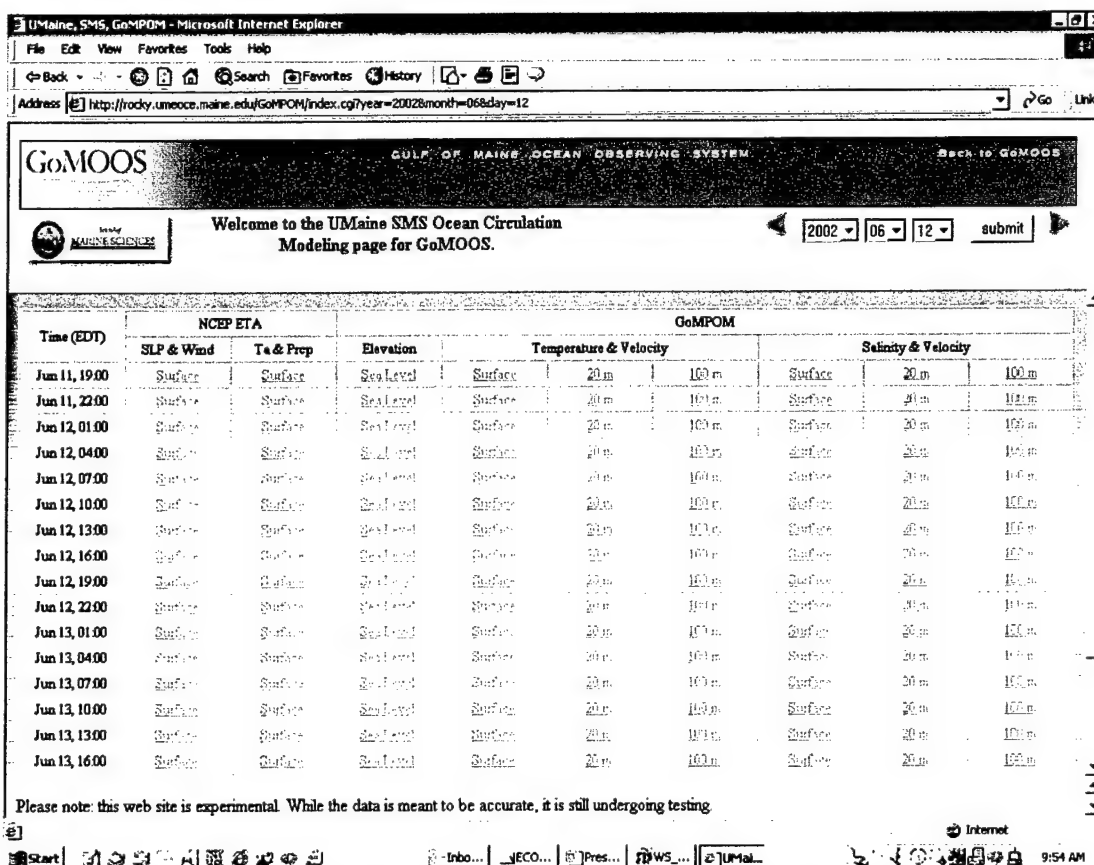


Figure 3. Daily web presentation of the Gulf of Maine circulation forecast.

### Data Assimilation

The most skillful forecasts are made by using data to constrain the model in the assimilative manner. The Gulf of Maine circulation forecast system now includes assimilation of the satellite SST, and it will also include assimilation of the surface velocity in the future. The later is being tested. Nevertheless, the scheme is also described in this section.

#### Assimilation of the SST

An algorithm similar to that of Kelley et al. (1999) has been incorporated since June 2001 to assimilate satellite AVHRR data into the model. The algorithm consists of three elements: an optimal interpolation scheme (Derber and Rosati, 1989; Behringer *et al.*, 1998); a mixed-layer adjustment (Chalikov *et al.*, 1996); and a Newtonian nudging. The optimal interpolation is used to determine a correction field for the model's top layer temperature by simultaneously minimizing two difference fields. One is the difference between the corrected temperature field ( $T_c$ ) and the model temperature ( $T_m$ ), and the other is between the corrected temperature field and the observed temperature ( $T_o$ ).

$$I = (T_c - T_m)^t \mathcal{R} (T_c - T_m) + (\mathcal{K} T_c - T_o)^t \mathcal{I} (\mathcal{K} T_c - T_o) \quad (1)$$

where the superscript,  $t$ , denotes the transpose matrix.  $\mathcal{R}$  and  $\mathcal{I}$  are the error covariance matrices for the model and data, respectively.  $\mathcal{K}$  is the transformation matrix that converts values at the model grid points to the observation locations. Minimization is achieved by using a preconditioned conjugate gradient algorithm (Gill *et al.*, 1981, Golub and Van Loan, 1989), which finds the solution iteratively. The mixed-layer adjustment projects the surface correction into the model's mixed-layer. When the corrected surface temperature is warmer than the model surface temperature, the correction is distributed throughout the mixed layer. When the corrected temperature is colder, the corrected temperature replaces the model temperatures down to the depth where they become equal. Newtonian nudging is used to slowly apply the correction field to the model temperature. The algorithm is steady and has produced robust sea surface temperature patterns since incorporation (Figure 4).

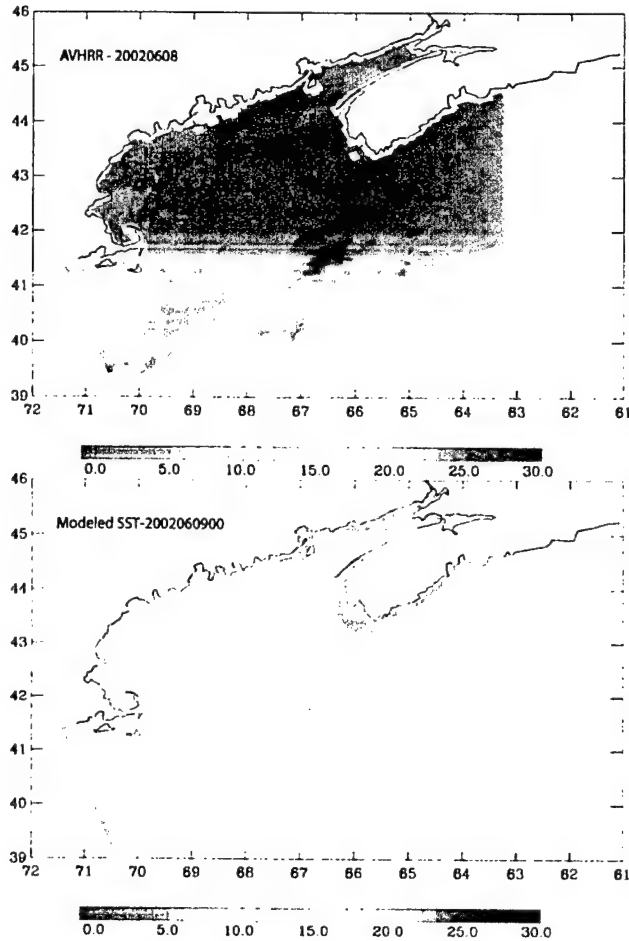


Figure 4. Comparison between the satellite SST and the model predicted SST.

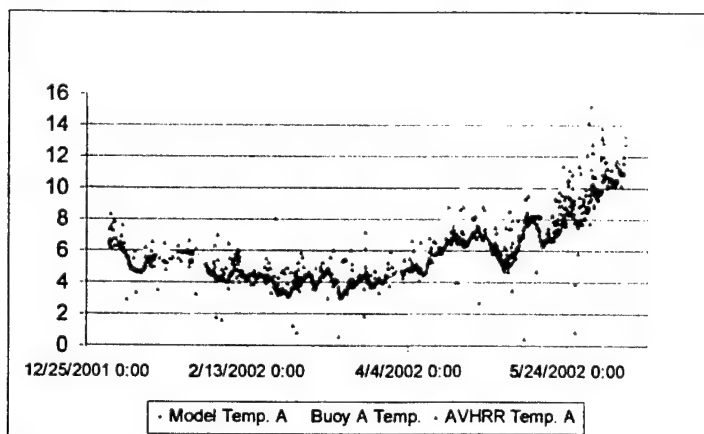


Figure 5. Comparison between the model, satellite and *in situ* SST at GoMOOS buoy A.

However, comparisons with *in situ* temperature show that the modeled temperature is colder (Figure 5). There are several possible factors: (1) satellite derived SST being colder than the *in-situ* SST, (2) colder satellite SST climatology that is used to from the analysis field when there is no real-time

SST in the past 8 days at any particular model grid, (3) artifact of the exceptionally cold temperature at cloud edges from the satellite SST, and (4) the assimilation scheme especially the nudging coefficient and the mixed layer adjustment. These factors are being examined carefully.

#### *Assimilation of the surface velocity*

CODARs are the high frequency radar units that can be used to map ocean surface currents. To assimilate the CODAR data into numerical ocean models, Lewis *et al.* (1998) used a shear stress approach, in which the modeled velocity is nudged towards the CODAR measured velocity by imposing an additional shear stress. It was noted that errors in the CODAR data could cause unrealistic horizontal divergence and sea level in the model. More recently, Lipphardt *et al.* (2000) found that the unrealistic divergence could be limited by first filtering the CODAR velocity field. Oke *et al.* (2000) used a simplified Kalman filter data assimilation system assimilates low-pass filtered CODAR velocity into a POM-based Oregon coast model. The non-homogeneous and non-isotropic forecast error covariance was empirically derived from an ensemble of typical model simulations.

We have developed a CODAR data assimilation scheme similar to that of Oke *et al.* (2000). Our first attempt is to assimilate the tidal residual current in the model. The scheme includes: a standard tidal analysis package to separate the tidal constituents both from the model output and from the CODAR velocity field, an incremental estimation of error covariance matrix and vertical cross-covariance vector based on the previous month's forecasts, an eigenvalue decomposition package to formulate an analyzed surface current field, and a statistical interpolation to project the analyzed surface current field vertically using the vertical cross-covariance vector. The three-dimension velocity correction field is then assimilated into the model by adding extra forcing to the pressure gradient term. The correction is introduced gradually, similar to the incremental analysis updating approach of Bloom *et al.* (1996).

#### *Analysis tools and forecast quality assessment*

##### *Model errors*

All nowcasts/forecasts are approximations to the true state of the ocean, and understanding the forecast errors is essential. Comparisons between the model prediction and the observation are routinely examined for sea level (Figure 6), SST (see Figure 5), subsurface temperature at GoMOOS moorings. In addition, the quality of the Eta forecast wind is

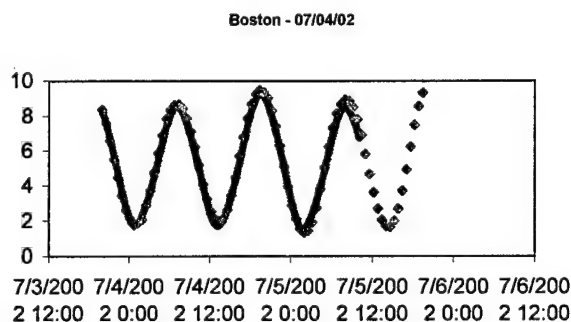


Figure 6. Comparison of model predicted sea level and NOS gauge data in Boston Harbor. Red – model; blue – gauge data.

examined by comparing with the GoMOOS and NOAA buoys.

### *Live Access Server (LAS)*

In addition to the routine forecasts, the Live Access Server (LAS) has been adapted to link with the model output archive, which allows to subset the forecast results interactively through the web (Figure 7). We are also developing an interface to link the LAS with a statistical package and the script that compares model results with buoy observations for archiving and evaluating the model errors. The script will become a critical component of the data assimilation and skill assessment package.

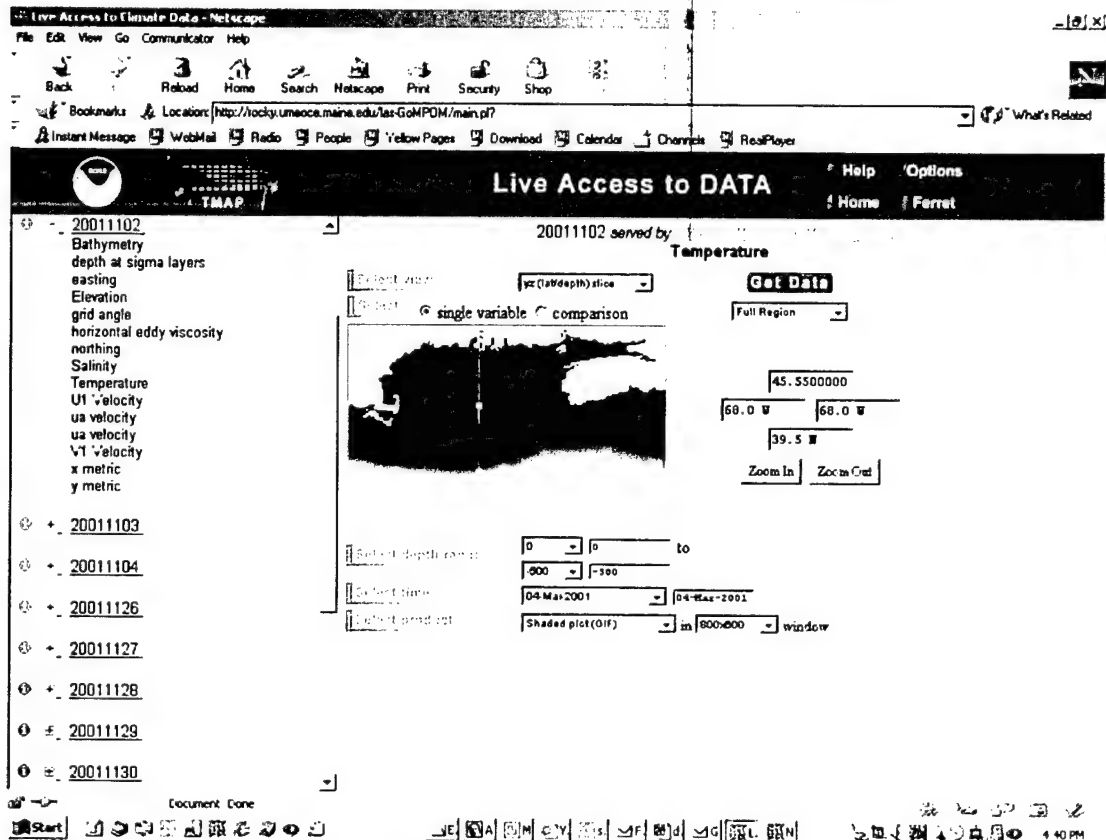


Figure 7. The LAS interface for the Gulf of Maine circulation forecast system.

### *Ongoing tasks*

#### *Assimilating CODAR measured surface velocity*

At present, the CODAR data, thereby the analysis field resulted from the optimal interpolation, appears rather patchy (Figure 8). The GoMOOS CODAR group is planning to reprocess the data. Filtering might be needed before the CODAR data can be assimilated. More work is needed to improve the robustness and to increase the computational efficiency of the scheme. We are working closely with the GoMOOS CODAR group to improve the surface velocity assimilation algorithm and to deliver more consistent forecast operationally.

### *Redundancy of the operational forecast*

Although both ETA and COFS are in the semi-operational mode at NCEP/NOAA, there have been occasional disruptions of the incoming data stream from NODC. We plan to duplicate the daily forecast with the meteorological and open ocean forcing from FNMOC and NAVO. We have started to archive SWAFS's and COAMPS forecasts over the Gulf of Maine region. The two parallel forecasts will not only minimize the interruption of our daily operation, but also provide quality assessment of ETA/COFS (NOAA) and COAMPS/SWAFS (Navy) forecasts over the region.

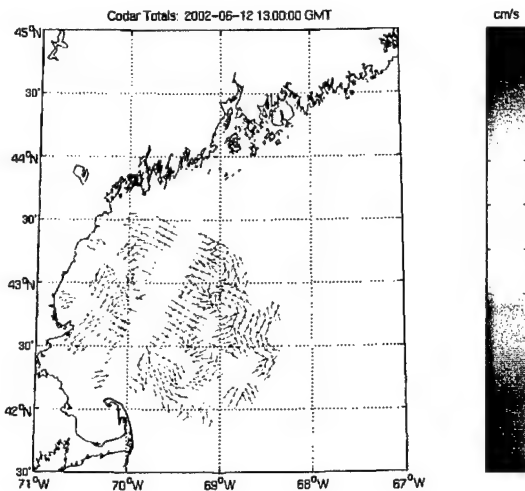


Figure 8. A sample of CODAR measured sea surface velocity field.

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## Surface Wave Forecast Model Development

*William Perrie, Bedford Institute of Oceanography*

### *Accomplishments and Status*

#### *Wave Model Implementation*

The operational NCEP model WaveWatch3 (WW3) was implemented for a coarse-resolution grid of  $1^\circ$  for the N. Atlantic. The coarse-resolution WW3 was nested to an intermediate-resolution  $0.2^\circ$  WW3 implementation for the NW Atlantic. This domain is the same as the domain for the fine-resolution COAMPS winds from the US Navy FNMOC, excluding its Gulf of Mexico region. The intermediate-resolution WW3 was nested to a fine-resolution  $0.1^\circ$  SWAN implementation for the Gulf of Maine and neighboring waters. Domains for fine- and intermediate-resolution grids are given in Figures 1-2. Figure 1 gives the COAMPS winds, near the peak of the January 14, 2002 meteorological "bomb" that passed through the region. Figures 2a-b present corresponding SWAN simulations for contours of significant wave heights ( $H_s$ ), wave directions and wave periods.

The composite WW3-SWAN system was just completed in Sept. 2002 and represents a significant technical accomplishment, because these two models have not been nested before. Thus, respective documentations for each model are unclear regarding actual nesting procedure and much of the work required careful painstaking examination of the codes to determine what each model was doing. Long script files (in excess of ~1000 lines) had to be constructed to orchestrate the nesting and the automation of the composite model.

#### *Winds*

Winds were taken from the COAMPS model, for the fine- and intermediate-resolution domains. For coarse-resolution grid points outside the COAMPS region, NOGAPS wind data were used. Scripts were constructed to allow automatic access to winds from the FNMOC web-site. These winds are needed to allow direct comparison with the models used by NAVO, for example WAM-SWAN, for the same storms.

Winds from *in situ* buoys were archived and comparisons / validations with FNMOC will be constructed in the Year3 Workplan on "Operational fine-resolution wave forecasting in the Gulf of Maine". The eight best RADARSAT SAR images for the winter of 2001-02 were archived and inverted for wind speed and direction, as well as wave spectra. A report is in preparation, by Paris Vachon at CCRS (Canada Centre for Remote Sensing), Mike Dowd (St. Andrews Biological Station) Will Perrie and Bechara Toulany, documenting this work, and comparisons with COAMPS winds, and *in situ* and model wave estimates.

#### *Wave Validation*

The field program consisted of deployment of a directional wave-rider (DWR) buoy, in shallow water (19m) in the shelf region off Yarmouth. The DWR was deployed from end-November, 2001 until mid-April 2002. Additional wave spectra (1-d and 2-d) were archived for this time period from measurements collected with a bottom-mounted RDI

ADCP at the same site. Additional Hs time series are available from GoMOOS buoy "L" in deep water (~100 m) off Yarmouth. Figures 3-4 show the DWR and ADCP instruments.

The biggest storm of the 2001-02 winter season occurred with the passage of winter meteorological "bomb" during 13-15 January 2002. Wave data were collected from the DWR, ADCP and buoy "L". Preliminary comparisons show that the instruments compare well with each other and with the wave model, (e.g. see Figure 5). Further study and validation of WW3-SWAN, for high waves, will be part of the Year3 Workplan.

Comparison of WW3-SWAN with models used by NAVO, for example WAM-SWAN, will be completed during the Year3 Workplan. These comparisons will include, statistics for the highest waves, for example the January "bomb", and also long-time series, for selected grid-points.

#### *Wave-Current Interactions*

The WW3-SWAN model has ability to couple with currents. POM model currents are available as part of GoMOOS and also from the NCEP COFS initiative. The model implementation has been set-up to allow this study for selected storms, for example Hurricane Erin, which passed over the Gulf Stream south of the GoMOOS area. This work will also be completed as part of the Year3 Workplan.

#### *How This Can Be Operationalized*

The scripts to access high quality wind fields, for routine high-resolution wave forecasts, must be fully tested and optimized. These scripts must be shown reliable and robust. They should access wind data from more than one NWP (Numerical Weather Prediction) source, for example, (a) US Navy COAMPS and NOGAPS winds, as well as several candidate data sources, (b) ETA model data, and (c) GEM model data from MSC (Met. Service of Canada).

Scripts have to format and pre-process wind data for driving the wave model. They also have to routinely run the composite WW3-SWAN wave model system, with nested grids, and post-process the outputs in formats that are acceptable to end-users. This is presented in the Year3 Workplan "Surface Wave Products for GoMOOS" by Smith et al.

As ongoing validation, scripts should access NDBC and MEDS buoy wave data sets, as well as buoy and Quikscat winds. As far as possible, an attempt should be made to quality control and re-format these data to verify with NWP wind fields. A further element of ongoing validation is comparison with NAVO wave products. Scripts should access outputs from NAVO web site, using WAM-SWAN simulations, driven by the same FNMOC winds, and statistics should be compiled, comparing WW3-SWAN with these wave products. Results should be presented on the GoMOOS web site.

An option to allow for wave-current interactions should be automated and available, for example for storms like Hurricane Erin, crossing the Gulf Stream in waters near the Gulf of Maine. Scripts should access currents from NCEP COFS model for the NW Atlantic,

including Gulf of Maine, as well as the operational GoMOOS currents displayed on the web site. Scripts should estimate impacts on wave simulations, due to wave-current interactions, compared to *in situ* wave measurements from buoys.

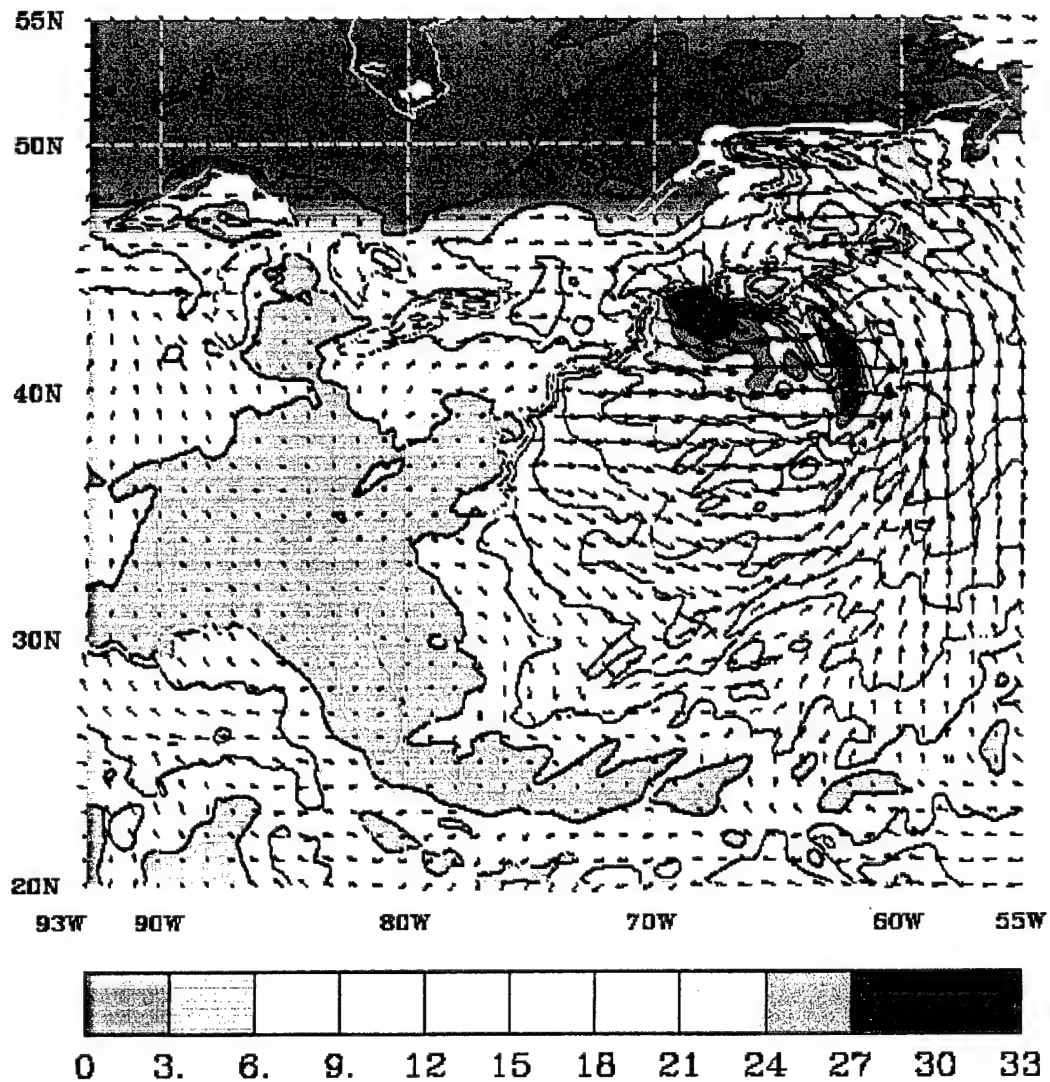


Figure 1. Wind speed and directions for 00 UTC on 14 January 2002, near the peak of a severe storm, or meteorological "bomb".

SIG. WAVE HEIGHTS (CONTOURS), WAVE DIRECTIONS (DIR. OF VECTORS), WAVE PERIODS (LENGTH OF VECTORS) AT 20020114 06

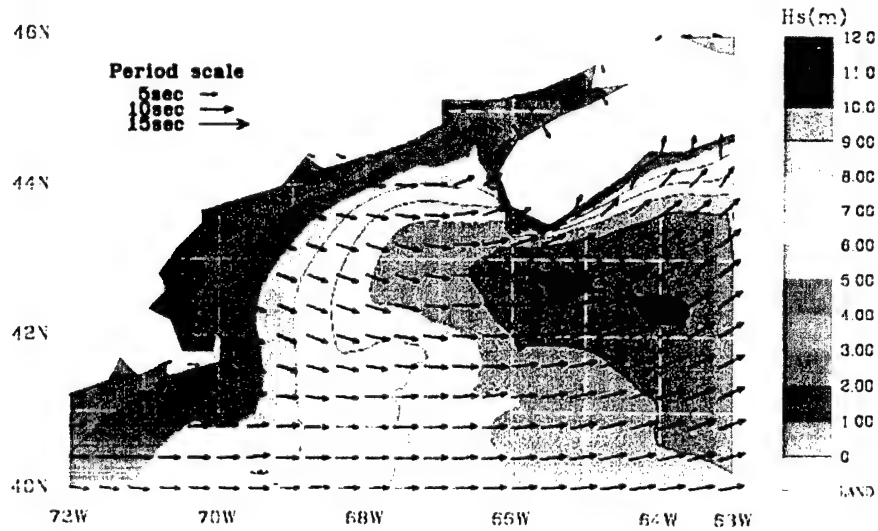


Figure 2a. As in Figure 1, for waves at 06 UTC on 14 January 2002, in the fine-resolution domain of the Gulf of Maine generated by the SWAN wave model.

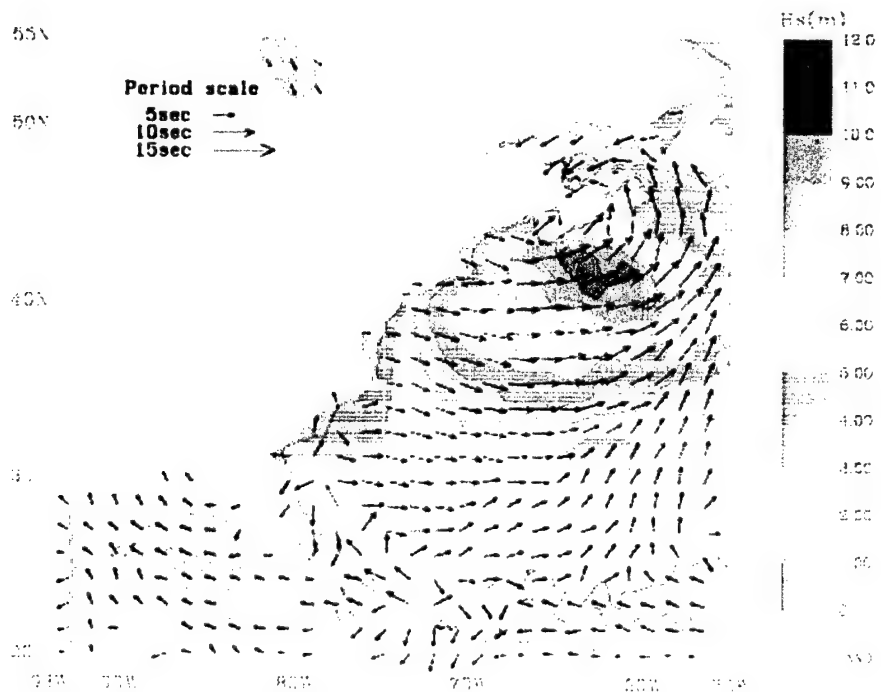


Figure 2b. As in Figure 2a, for domain of intermediate-resolution grid. This is defined by COAMPS forecast domain for wind fields.



Figure 3. DWR buoy with CCGS Cornwallis standing by off Yarmouth, NS.

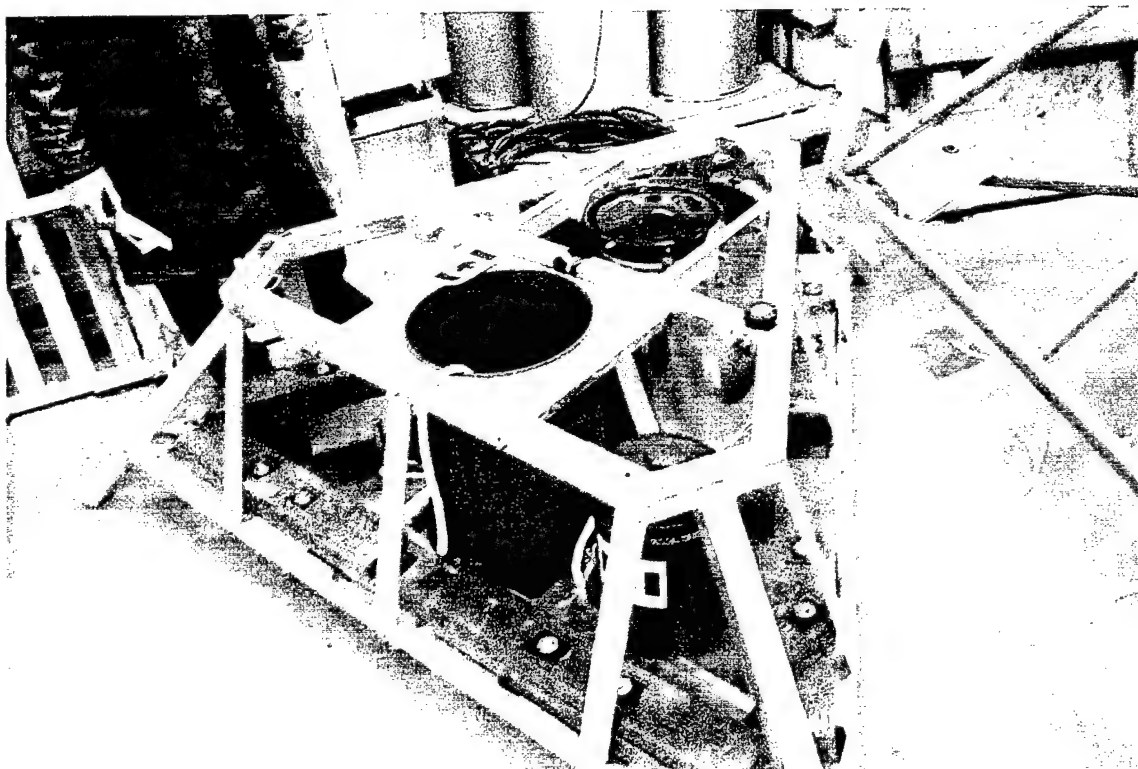


Figure 4. Frame containing bottom-mounted ADCP instrument.

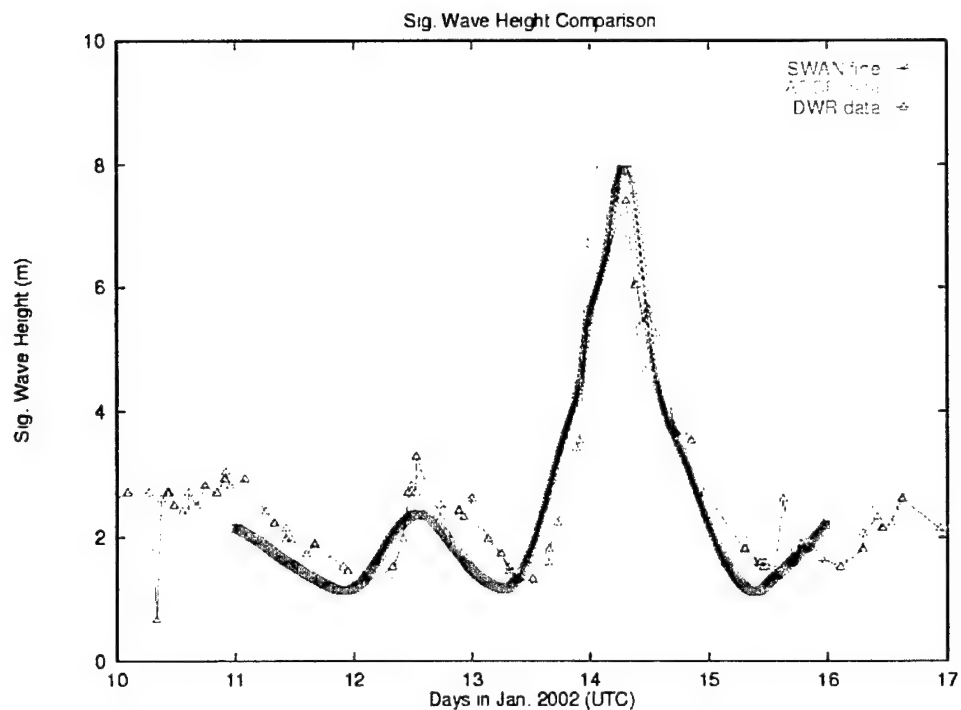


Figure 5. Comparison of  $H_s$  time series from DWR, ADCP and SWAN wave model at the BIO mooring in 19m water depth. This time series corresponds to the storm given in Figure 1-2.



## Nutrient Monitoring

Dave Townsend, University of Maine

### Introduction

The first phase of the contract to the University of Maine for nutrient monitoring is reported here. It includes a description of a subcontract to The Friends of Casco Bay to collect water samples from Casco Bay for the analysis of dissolved inorganic nutrients. The subcontract was issued in 2000, for an 18 months period. That contract has subsequently been managed directly by GoMOOS. In addition, we report here on initial results of testing newly developed technology for *in situ* monitoring of nutrients.

### Nutrient Analysis of Casco Bay Samples

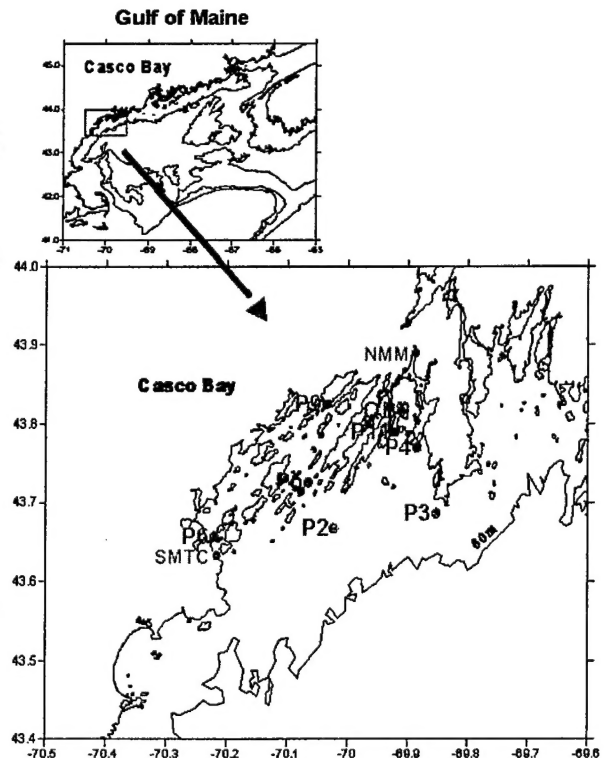
This portion of our project involves the close collaboration with the Friends of Casco Bay at Southern Maine Technical College in South Portland, Maine, to monitor nutrients throughout Casco Bay 15 times per year, starting in February 2001. They collect water samples from a small boat at various stations throughout the Bay (as shown in the Figure). Sampling has been biweekly in the warmer months and monthly during winter. In addition, daily samples are collected off the dock in South Portland. Samples are delivered frozen to our biological oceanography laboratory in Libby Hall at the University of Maine in Orono where they are analyzed using standard autoanalyzer techniques. This sampling program continues as of this writing (Oct., 2002). Results of these analyses are posted on the web at:

<http://grampus.umeoce.maine.edu/gomoos/stnmap.htm>.

### Calibration and Testing of *in situ* Nutrient Analyzers:

In the spring of 2002, GoMOOS purchased two newly developed and manufactured EcoLabs nutrient sensors. These newest models are capable of measuring up to 4 nutrients in a single unit, whereas models previously available were capable of only a single analysis. Our units are designed to analyze 4 nutrients ( $\text{NO}_3+\text{NO}_2$ ,  $\text{NH}_4$ ,  $\text{SiO}_4$ ,  $\text{PO}_4$ ) *in situ*, under programmatic control. Before the instruments can be deployed on any of the GoMOOS moorings, we first need to test them fully, performing laboratory analyses to determine calibration coefficients and analytical sensitivities.

Our laboratory bench tests of the instruments have involved simulated deployments, whereby the instruments are programmed to sample standard-solution samples over a 5-10 day period. Like any new technology, we have been experiencing



some technical difficulties with these new sensors, and our confidence in the accuracy and precision of each of the nutrient analyses does not yet allow us to recommend they be used in a field test on an actual mooring deployment. First, the ammonia analytical capability is in doubt: the manufacturer has recalled the ammonia sensor unit, and we have yet to receive word of when we might expect to receive shipment of a redesigned unit. Phosphate measurements are problematic, which the manufacturer suspects is the result of subtle chemistry problems that they are working on. Nitrate analyses are noisy, but they show promise. We believe that the difficulties in nitrate measurements are the result of the cadmium reduction columns, which reduce nitrate to nitrite, the chemical species actually analyzed, and we are continuing to experiment with potential solutions in consultation with the manufacturer. Silicate measurements are also noisy and, the manufacturer and we believe, may be remedied by a mix of more frequent flushing cycles, or a slightly altered chemical treatment.

Despite these initial problems, we must remind ourselves that there are no competing technologies on the market today. The basic chemical theory of the methodology is sound, and we are convinced that the engineering design and craftsmanship are superb. We simply need a longer testing period before the machines "settle down" and deliver solid data. We also emphasize that the manufacturer is working closely with us, and we expect to be reporting progress soon. Once fully debugged, we expect that we will be ready to deploy the sensors on our GOMOOS buoys, hopefully, by early next year.

## **Monitoring Upper Trophic Levels and GoMOOS/RARGOM Report**

*Lewis S. Incze, Bigelow Laboratory for Ocean Sciences*

### *Results of phase 1 funding*

The objective of this component was to do a preliminary survey of zooplankton sampling conducted in the Gulf of Maine by the Northeast Fisheries Science Center in Woods Hole (NOAA/NMFS/NEFSC). The survey included a tabulation of past sampling (temporal and spatial properties) with CPR and bongo nets; and a preliminary comparison of data from the two programs (do the two methods/programs show similar spatial and interannual patterns of abundance?). The goal is to forge a collaboration between NOAA, DFO and GoMOOS environmental sampling to maximize the information gained. This includes redesigning efforts where there is mutual agreement. The analysis shows where some changes ought to be considered, and some funding is being provided in 2003 to convene an appropriate working group to address this topic. Looking critically at the data and establishing a working relationship among investigators was the first step toward meeting this goal. A report was issued to GoMOOS in February in Powerpoint format with sixteen figures and tables plus explanatory text. GoMOOS intends to make the report available on the web. It is currently available through the PI's web site and was submitted to collaborators at NOAA fisheries: David Mountain in Woods Hole and Jack Jossi in Rhode Island.

The report on the Gulf of Maine Ocean Observing System workshop held in Woods Hole in 2001 was finalized in April 2002. The workshop had been sponsored by GoMOOS and convened by the Regional Association for Research on the Gulf of Maine. Printed copies were delivered to GoMOOS in August 2002. The meeting itself, and the "rapid response paper" that followed, achieved some of the immediate goals of the workshop effort. The final report provides a written record of several suggestions that remain useful for future consideration by GoMOOS and other observatories.

### *Operational Considerations*

Integrating the high temporal resolution of GoMOOS data with the broad measurement capabilities of ship surveys by NOAA and DFO should remain an important operational goal for GoMOOS. Consideration should be given to all measurements that can be made efficiently, but the linkages to biological sampling must be an especially high priority. Collaboration in sampling should lead to benefits for research and management. This need is particularly acute in view of the current pressures to move from "fisheries management" toward a goal of "integrated ocean management". The latter demands much greater understanding of the ecosystem and testing of that knowledge. While it is logical to look toward the largest federal programs for this integration, connections to the coastal zone and land-sea margin must also be developed.

### *GoMOOS/RARGOM Report*

The Regional Association for Research on the Gulf of Maine (RARGOM) sponsored a workshop in January, 2007 discuss the need for a coordinated observing system in the Gulf of Maine. The resulting report (RARGOM-98-1) called for (1) an expansion of

monitoring stations and technologies built around existing infrastructure, (2) a coordinated mechanism to access observations, (3) consideration of the interrelated aspects of Gulf of Maine ecosystems, and (4) a repository for local monitoring efforts, providing a regional context. The rationale and many of the design features are now integrated into the Gulf of Maine Ocean Observing System (GoMOOS).

In January 2001, RARGOM and GoMOOS co-sponsored a follow-up workshop. The resulting workshop report (RARGOM Report 02-1) provided a thematic summary of recommendations that emerged from working groups on (1) water quality, (2) primary productivity, (3) zooplankton, fish and upper trophic levels, (4) data and information, and (5) modeling. The report focuses on the scientific aspects of the system design and development. These have become the basis for further development of the system.